U.S. Department of Transportation

Federal Aviation Administration

Operational Evaluation Report

for the

DFW Multisensor Fusion

Runway Status Light System

(RWSL)

OPERATIONAL EVALUATION REPORT

APPROVAL SIGNATURE PAGE

RWSL

APPROVAL SIGNATURES		
PARTICIPANT	NAME	DATE
[RWSL Project Organization]		
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1 General Description of Operational Need

The Federal Aviation Administration (FAA) is dedicated to the goal of enhancing runway safety while ensuring airport capacity. The reduction of runway incursions has been identified as one of the most important aviation safety initiatives and is crucial for the improvement of runway safety.

Runway status lights may offer a means of reducing the severity of runway incursions and preventing runway accidents. They do so by indicating to pilots and vehicle operators that a runway is unsafe for entry or crossing or that a runway is unsafe for departure, thereby improving situational awareness.

2 Operational Concept

The Runway Status Light System (RWSL) is designed to be an all-weather automatic system providing safety backup to controllers, pilots, and vehicle operators by improving situational awareness via a visual alert indication to the pilots and vehicle operators in the runway environment. RWSL is not intended to increase controller workload nor decrease airport capacity, but rather works in concert with existing and new pilot procedures to enhance runway safety. The lights are driven automatically using computer processing of integrated surface and terminal surveillance information. The RWSL software detects the presence and motion of aircraft and surface vehicles on or near the runways, assesses any possible conflicts with other surface traffic, illuminates red runway-entrance lights (RELs) if the runway is unsafe for entry or crossing, and illuminates red takeoff-hold lights (THLs) if the runway is unsafe for departure. The system turns the lights off automatically as appropriate when the runway is no longer unsafe. One goal of runway status lights is to reduce the number of runway incursions without interfering with normal and safe airport operations.

Runway-entrance lights (RELs) are in-pavement fixtures situated at selected runway-taxiway intersections and face the taxiways that intersect runways. RELs illuminate red when the runway is unsafe to enter; they are off otherwise. For each high-speed operation, RWSL determines whether it is a departure or an arrival, and defines a safety zone in front of the aircraft. RELs for runway entrances that lie within that safety zone are illuminated to keep other aircraft or vehicles from entering at that position. To avoid interference with fundamentally safe operations, the RELs are extinguished just before the high-speed operation clears the intersection, when it is safe to start motion into the intersection, allowing controllers to use anticipated separation.

Takeoff-hold lights (THLs) are situated at selected full-length and intersection takeoff-hold positions. THLs are also in-pavement fixtures, installed alongside the runway centerline for approximately 1000 feet facing aircraft in the takeoff hold position. This configuration is intended to allow for differing visibility conditions and incursion scenario timings. If required locally, as is the case for DFW, additional THLs may be positioned to accommodate multiple departure runway entrances. THLs illuminate red when the runway is unsafe for departure because it is currently occupied or about to be occupied by entering or crossing traffic; they are off otherwise. To avoid interference with fundamentally safe operations, the THLs are extinguished just before the blocking or crossing traffic clears the runway, when it is safe for the departure to commence, allowing controllers to use anticipated separation.

In all cases, runway status lights indicate runway status only; they do not communicate a clearance. Clearance is provided by air traffic control as under current local and national procedures. A pilot or vehicle operator who sees a status light turn off must still obtain clearance before proceeding. If clearance has been issued, but a status light is illuminated, the pilot or vehicle operator should stop and verify the clearance with the tower before proceeding. This will all be covered in the training material to all controllers, pilots, and vehicle operators.

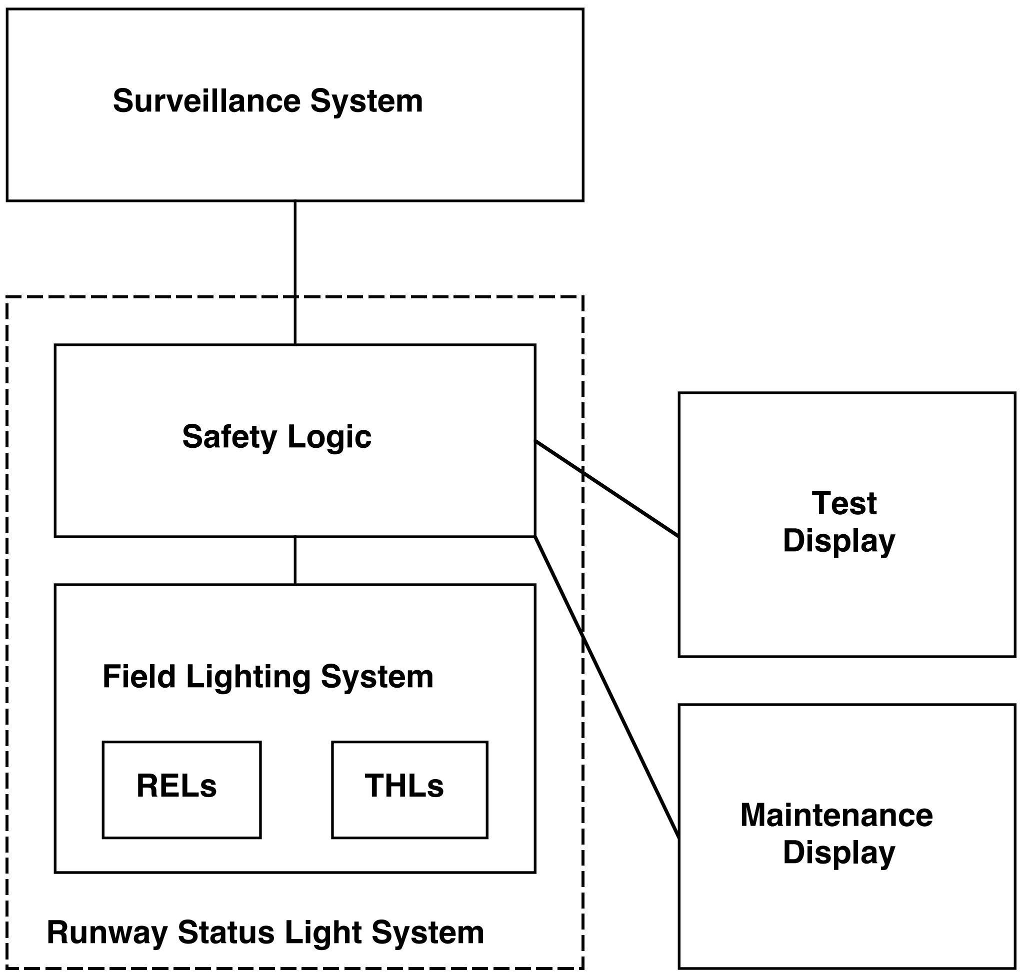

Figure 1. Runway Status Light System conceptual top-level diagram.

Figure 1 shows a top-level conceptual diagram for RWSL. The system is driven by surveillance information obtained from an external surveillance system. The surveillance uses information from terminal radars, from a transponder multilateration system, and from a surface primary radar system to provide position and other information for all aircraft and transponder-equipped vehicles on and near the airport surface. Transponders must be on in the movement area for the multilateration system to provide reliable surface surveillance to RWSL. RWSL contains safety logic that processes the surveillance and commands the field lighting system to turn the runway-entrance and takeoff-hold lights on and off in accordance with the motion of the traffic.

THLs were not part of the initial DFW operational evaluation. Correct THL operation depends on surveillance based on a combination of beacon and primary returns. An interim feed from the current ASDE-3 was added to the formerly beacon-only DFW RWSL surveillance system, but insufficient operational experience existed with this testbed system to assure that the RPMT system requirements for THL operation could be met without further system optimization. When greater THL reliability can be demonstrated over a longer period of time, then THLs may be revisited.

3 Research Plan Outline

RWSL is being developed by MIT Lincoln Laboratory under contract to the Federal Aviation Administration in order to assess its suitability in an operational environment. This assessment is planned to occur in three phases: engineering development, shadow operations, and operational evaluation. Each phase has a defined system implementation, test procedures, technical goals, and entrance and exit criteria. The phases are described briefly in this section.

3.1 Engineering Development

In the engineering development phase, the core functionality of the system was developed, tested, and demonstrated in a laboratory environment. Surveillance data were recorded at a field site to provide realistic inputs to the laboratory system. Software was written to read the recorded data, to process the surveillance information, to identify the operational state of each aircraft or vehicle on or near the runways, to project the range of expected behavior of the aircraft or vehicles, to determine which runway status lights should be illuminated, and to drive a laboratory display of the airport surface traffic and runway status light states.

The engineering development test is described separately in the engineering development test plan [5]

3.2 Shadow Operations

The shadow operations phase emphasizes real-time but non-operational use of the RWSL safety logic and displays in the field environment. Live surveillance data were introduced to the RWSL safety logic software to drive displays showing the airport traffic motion and status light operation in real time. No field lighting system was active, however, and no interaction with operational controllers, pilots, or vehicle operators occurred. Instead, the system was shown in a non-operational environment to controllers and pilots to elicit their assessment of the operational concept and suitability. Feedback and quantitative assessment from this phase allowed fine-tuning of the system dynamics in preparation for the operational evaluation phase.

The shadow operations test is described separately in the shadow operations test plan [6].

3.3 Operational Evaluation

The operational evaluation phase tested the operational suitability of the runway status light system. A field lighting system was installed on the airport. The lighting system was tested prior to operational evaluation. Pilots and vehicle operators viewed lights, which were driven dynamically by the RWSL safety logic software in response to live surveillance. A manual shutoff switch was available in the tower to disable the system. Controller supervisor, voluntary controller, pilot, and vehicle operator feedback were elicited to support determination of the operational suitability of the RWSL system at DFW. Technical performance data were collected and summary performance statistics will be generated by automated test software.

The operational evaluation will be described in detail in the following sections.

4 Performance Measures

Two classes of performance measures were collected during the operational evaluation: operational feedback and technical performance.

Operational feedback was the primary focus during the operational evaluation. This information consists of comments, notes, and observations, as well as responses to questionnaires from controller supervisors, voluntary controller participants, pilots, vehicle operators, test team members, evaluators, and other observers. The operational feedback determines when and to what extent RWSL affects the normal operation of the airport.

Technical performance data were used to monitor system technical performance and to provide a context for the operational feedback. The technical performance metrics for the operational evaluation are defined in the engineering development test plan.

5 Operational Evaluation Roles and Responsibilities

5.1 FAA ATO

The sponsor of the RWSL program and the operational evaluation activity was FAA ATO. The sponsor was responsible for all program management functions including tasking and directing the team members in the conduct of the operational evaluation and hosting meetings of the RWSL team. ATO interfaced with the DFW FAA staff and management regarding scheduling of the ATC Supervisors for test sessions.

5.2 MIT Lincoln Laboratory Team

The MIT Lincoln Laboratory operational evaluation team included the technical lead of the project, the test administrator, the site coordinator, the human factors specialists, the software developers, and the analysts. This team had prime responsibility for insuring a successful operational evaluation. Members of this team worked closely with DFW personnel for the duration of operational evaluation to maintain the system and to collect and record the data. This team interacted with the Field Lighting System (FLS) team and surveillance system vendors as necessary. The MIT Lincoln Laboratory resident DFW site coordinator assigned specifically to support the RWSL program served as the DFW point of contact for the operational evaluation at DFW. The MIT Lincoln Laboratory site coordinator interacted with the airlines and airport manager to schedule training of airline pilots and vehicle operators. The site coordinator also coordinated with pilots, vehicle operators, and controllers to set up methods for obtaining operational feedback. The MIT Lincoln Laboratory team coordinated throughout with the airline pilots unions Allied Pilots Association (APA) and Airline Pilots Association (ALPA).

5.3 FAA DFW Team

An ATC supervisor team was established, and consisted of eight (8) DFW tower supervisors. The team members kept their membership and participation in the RWSL program throughout the evaluation phases at DFW from local optimization, through shadow operations, and to the conduct, completion, review, and reporting of operational evaluation activities and results. The team underwent appropriate training and assisted in tuning the runway status light system before the formal operational evaluation began. The team performed as subject matter experts during operational evaluation. They facilitated access to controllers to obtain operational feedback on a non-interfering basis.

The DFW air traffic controllers underwent training to allow them to understand the operational aspects of RWSL. For these controllers, filling out questionnaires or actively participating in the RWSL evaluation was optional and voluntary. DFW Airway Facilities supported the installation and maintenance of RWSL hardware or cabling in the west control tower by providing access to the equipment rooms and ensuring the RWSL work does not interfere with operational systems.

5.4 Pilots and Airlines, including pilots' unions

All pilots who fly in or out of DFW during the RWSL operational evaluation had access to RWSL training material. Through coordination with the RWSL team, the airlines trained their pilots and motivated them to assist in the evaluation by submitting questionnaire responses, in written form or online, in a timely fashion during the operational evaluation. Pilots not flying for an airline were also asked to submit questionnaire responses. Pilots were also verbally interviewed. The questionnaires and interview questions were given to the pilots' unions for their information prior to the operational evaluation. Pilots were requested to leave aircraft transponders on while in the movement area.

5.5 Vehicle Operators

All vehicle operators approved to operate in the runway environment underwent RWSL training. The DFW airport administration office managed the training and motivation of vehicle operators to assist in data collection activities such as filling out questionnaires. Some airport vehicles were equipped with transponders and the drivers instructed by the DFW airport administration office to leave the transponders on during the daily testing periods in order to assist with completeness of multilateration system data.

5.6 DFW Airport Authority

The DFW Airport Authority coordinated RWSL training for all approved vehicle operators.

5.7 Research Project Management Team

The Research Project Management Team (RPMT) had authority for determining the progression of the program from phase to phase. Representatives from the RPMT were invited to observe the operational evaluation. The RPMT was briefed with the results of the test. The RPMT is responsible for assuring the confidentiality of all recorded information. At the conclusion of operational evaluation, the RPMT will review all available data and will provide an assessment of the operational suitability of RWSL for FAA management review and approval.

5.8 FAA Technical Center

The FAA William J. Hughes Technical Center (WJHTC) assisted in the development of the test methodology and in the training and data collection activities during the operational evaluation at DFW. They worked in collaboration with the MIT Lincoln Laboratory test team of human factors experts and safety logic experts. They provided an independent assessment and oversight of the test.

5.9 FAA Flight Standards

FAA Flight Standards was responsible for determining the acceptability and suitability of airfield light placement, light configuration, and the affect of such lights on pilots. They interacted with FAA ATO and MIT Lincoln Laboratory. They supervised the RWSL flight tests.

5.10 Field Lighting System Vendor

Siemens Airfield Solutions, the Field Lighting System (FLS) vendor, performed initial tests on the FLS. The FLS interface with the RWSL system followed an interface specification given in the RWSL FLS RFP [1].

5.11 Surveillance Vendors

Sensis Corporation has built, installed, and adapted a portion of its ASDE-X system for DFW. Sensis was responsible for any re-engineering required for the ASDE-X equipment.

Primagraphics Ltd. has built and adapted its CAT Track radar plot extraction and tracking system for the west DFW ASDE-3.

6 System Components

RWSL system components were located on the airfield, in the southwest lighting vault, and in the west and center towers. The system used surveillance inputs covering the west side of the airport and approach areas.

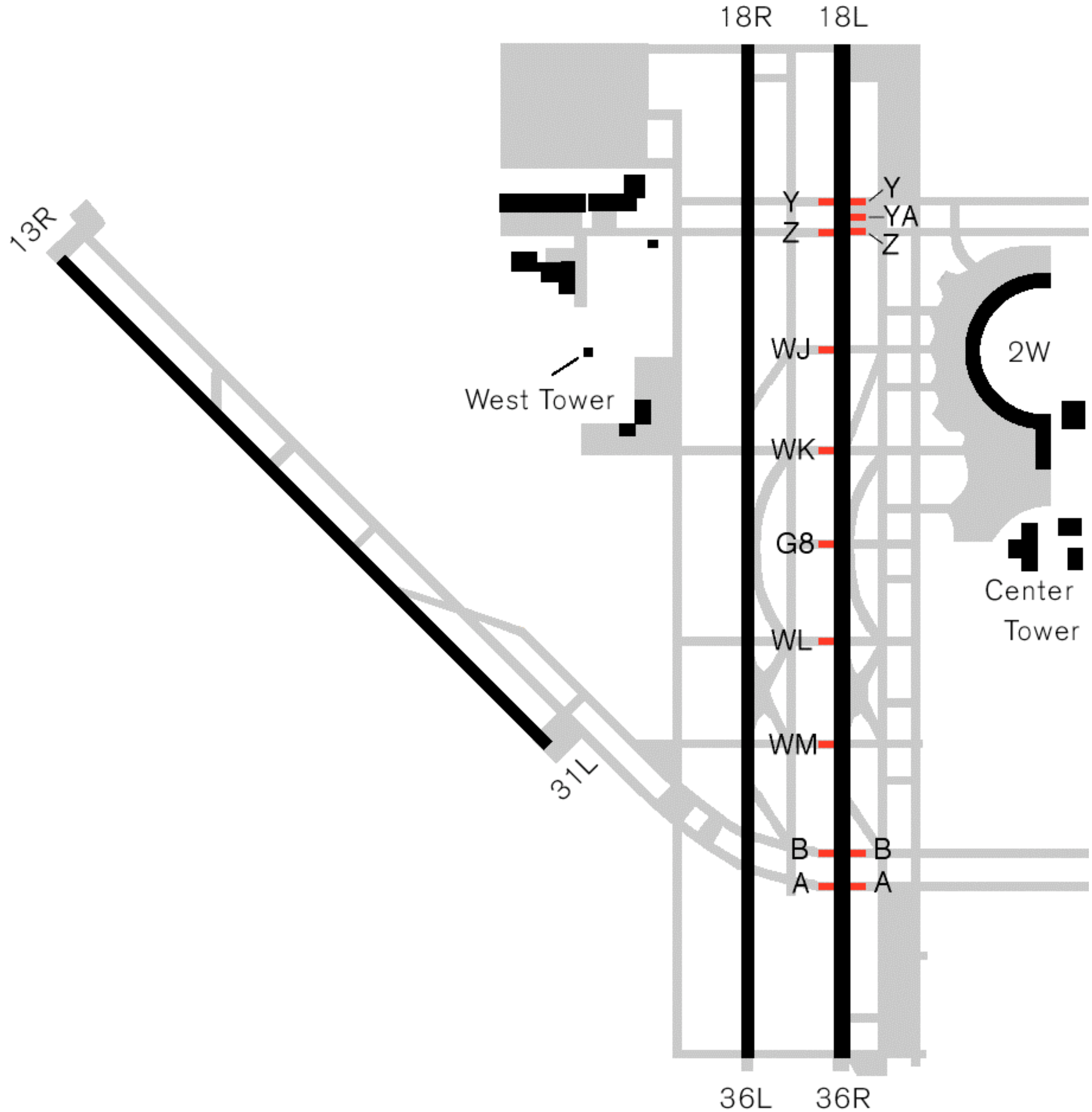

Figure 2. Adaptation for operational evaluation on DFW runway 18L/36R. RELs at equipped runway entrances are shown here in red.

6.1 Airfield Components

The RWSL Field Lighting System (FLS) includes RELs and their associated individual light controllers, installed in designated taxiways along runway 18L/36R (as shown in Figure 2). The lights and controllers are installed in fixture bases that also contain the isolation transformers to connect to the dedicated RWSL airfield lighting cable.

6.2 Southwest Vault Components

The Airfield Lighting Equipment installed in the southwest vault includes two (2) master cable controllers, two (2) constant-current regulators, the field lighting computer, the manual shutoff relays (that turn the regulators on or off), and the associated RWSL fiber optic interface devices.

6.3 West Tower Components

The RWSL equipment temporarily installed in the DFW west tower included one (1) 12-inch Apple iBook laptop computer and one (1) manual shutoff switch with cover. Displays (described below) were made available to non-operational personnel only.

6.3.1 Laptop Computer

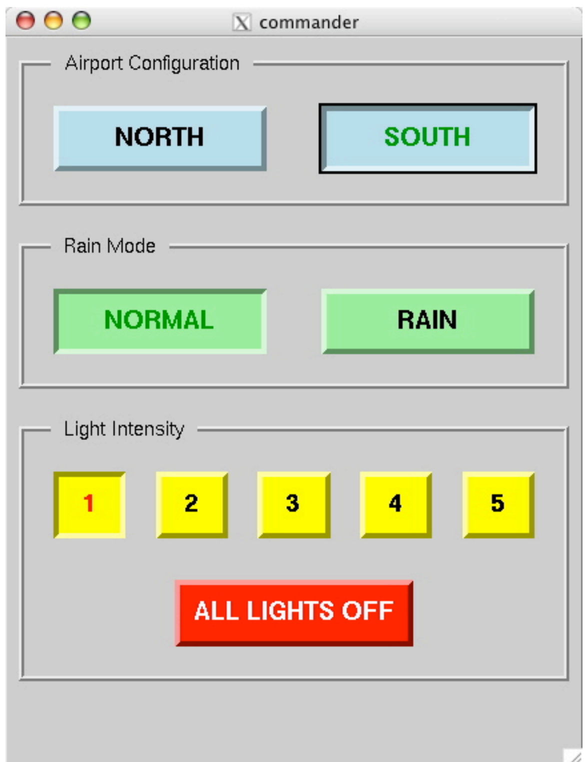

Figure 3. RWSL lighting control display.

The laptop computer provided lighting control via the keyboard. It was installed in the tower cab. Lighting control allows selection of runway configuration for north or south flow, a soft-off button, selection of operational mode for normal or heavy rain conditions, and setting the light intensity to one of five levels. The laptop also provided a display of the selected settings, as shown in Figure 3. The laptop computer also provided a Traffic and Status Display that shows the states of the runway-status lights, runway and taxiway outlines, and the traffic in plan view, as shown in Figure 4. Aircraft and surface vehicles are shown as icons. Data tags show flight ID and equipment type if available, otherwise a tail number and equipment type if available. The data tags can also optionally show altitude in feet above ground level and speed in knots.

Aircraft on final approach are depicted on an approach bar near the arrival end of the runway. The approach bar represents five nautical miles of approach space. The displays may be zoomed, panned, rotated, or recolored as needed to optimize usability. Multiple windowing capability is also available for expanded views of interesting areas.

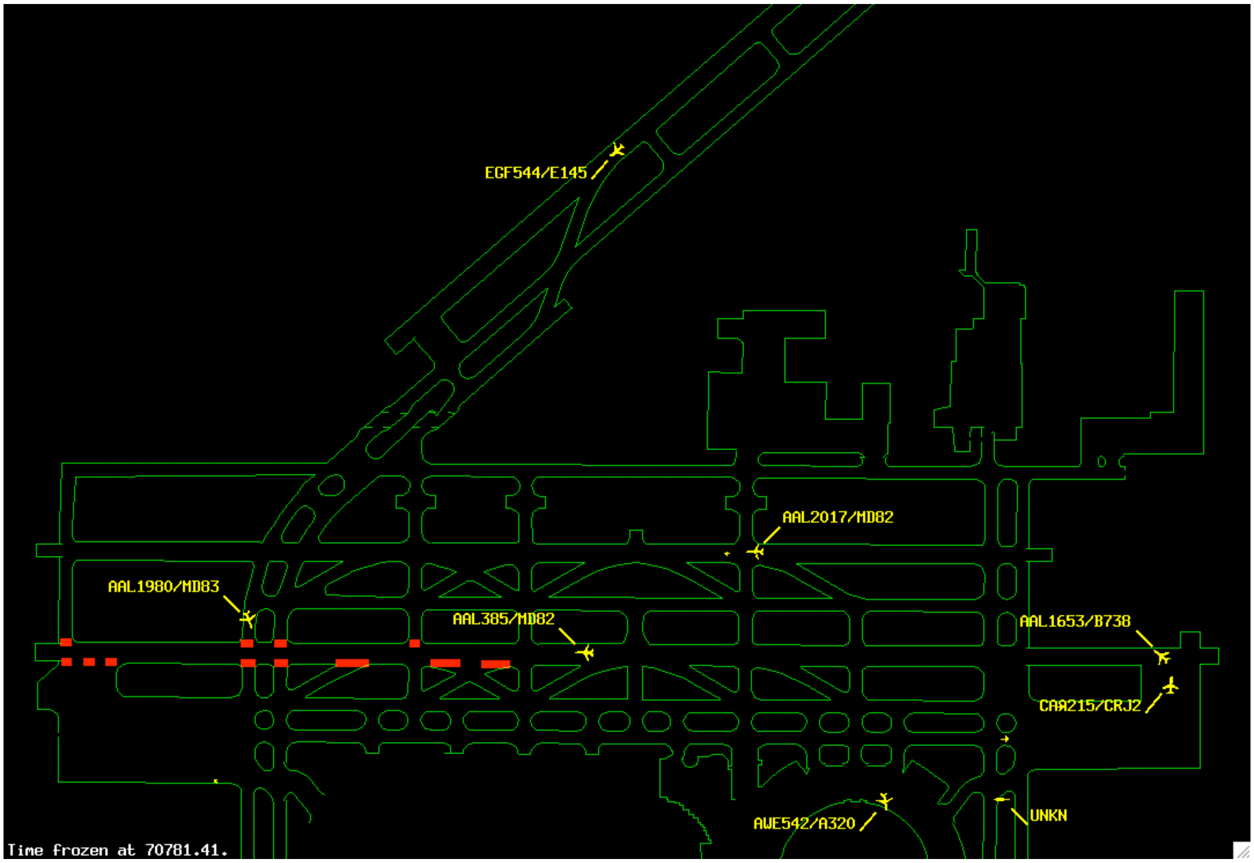

Figure 4. RWSL traffic and status display.

Software adaptation limited the Traffic and Status Display presentations to represent the actual operational evaluation deployment of RWSL on 18L/36R (as shown in Figure 2) for the purpose of depicting the light states and the field lighting control status. The laptop is shown in Figure 5.

Figure 5. Apple iBook laptop computer for use by test administrator.

6.3.2 Manual Shutoff Switch

The manual shutoff switch remotely controlled the on/off state of the constant-current regulators (by activating co-located relays) in the southwest lighting vault, via a dedicated communications circuit that bypasses all other airport and RWSL equipment. The manual shutoff switch with cover is shown in Figure 6.

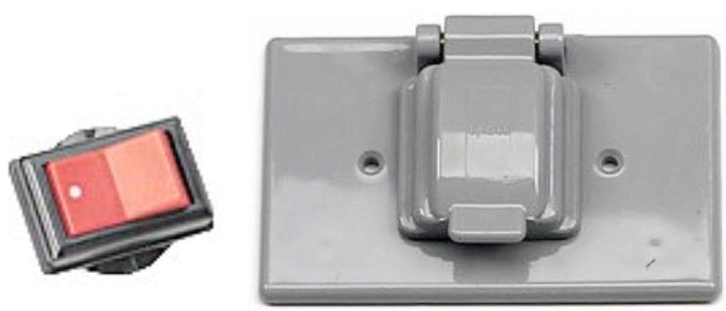

Figure 6. Manual shutoff switch and cover.

6.3.3 Laptop Computer and Manual Shutoff Switch Installation Requirements

Both the laptop computer and the manual shutoff switch required power and communications cable installation. A security cable was available for the laptop, but was not used.

6.4 Center Tower Equipment

The RWSL hardware used during shadow operations tests was maintained for use during operational evaluation. It includes:

- One (1) Sun Blade 150 computer (pizza box configuration)
- One (1) Sun Blade 2000 computer (tower configuration)
- Two (2) General Digital Genstar 20" flat panel monitors
- One (1) network switch
- Two (2) pairs of Raritan Cat5 Reach KVM extenders
- One (1) tape drive
- Two (2) keyboard/mouse sets
- One (1) Sony AIR-8 receiver
- One (1) AOR AR-3000A receiver (see Figure 10)

In addition to the shadow operations hardware, the following equipment was located in the center tower for interfacing with the field lighting system during operational evaluation:

- One (1) Comtrol DeviceMaster RTS device server (see Figure 7)
- One (1) Omnitron FlexPoint 100Fx/Tx ethernet-to-fiber media converter (see Figure 8)

Figure 7. Comtrol DeviceMaster RTS device server.

A Lantronix UDS100 had initially been installed, but proved to be unreliable and was replaced by the Comtrol product.

During operational evaluation, one of the 20" flat panel monitors was available to be installed in the ASDE-X equipment room for system control, but was not used. The other continued to be mounted on a Strongarm mount (see Figure 9) in the center tower cab.

In addition, two Traffic and Status Display Units (the on-screen display is described in Section 6.3.1) were also available for educational use in the center tower. These display units were to be removed or stowed if the center tower had been put into operational use.

Figure 8. Omnitron FlexPoint 100Fx/Tx ethernet-to-fiber media converter.

Figure 9. Strongarm monitor arm.

6.5 Deinstallation

The RWSL hardware installed in the DFW West and Center Towers for operational evaluation were removed or stowed in non-interfering locations when not in use. The keyboards and displays were able to be positioned out of the way, or removed easily within 30 minutes. At the end of the operational evaluation tests, all installed hardware was scheduled to be removed entirely when directed by the FAA and the DFW airport authority.

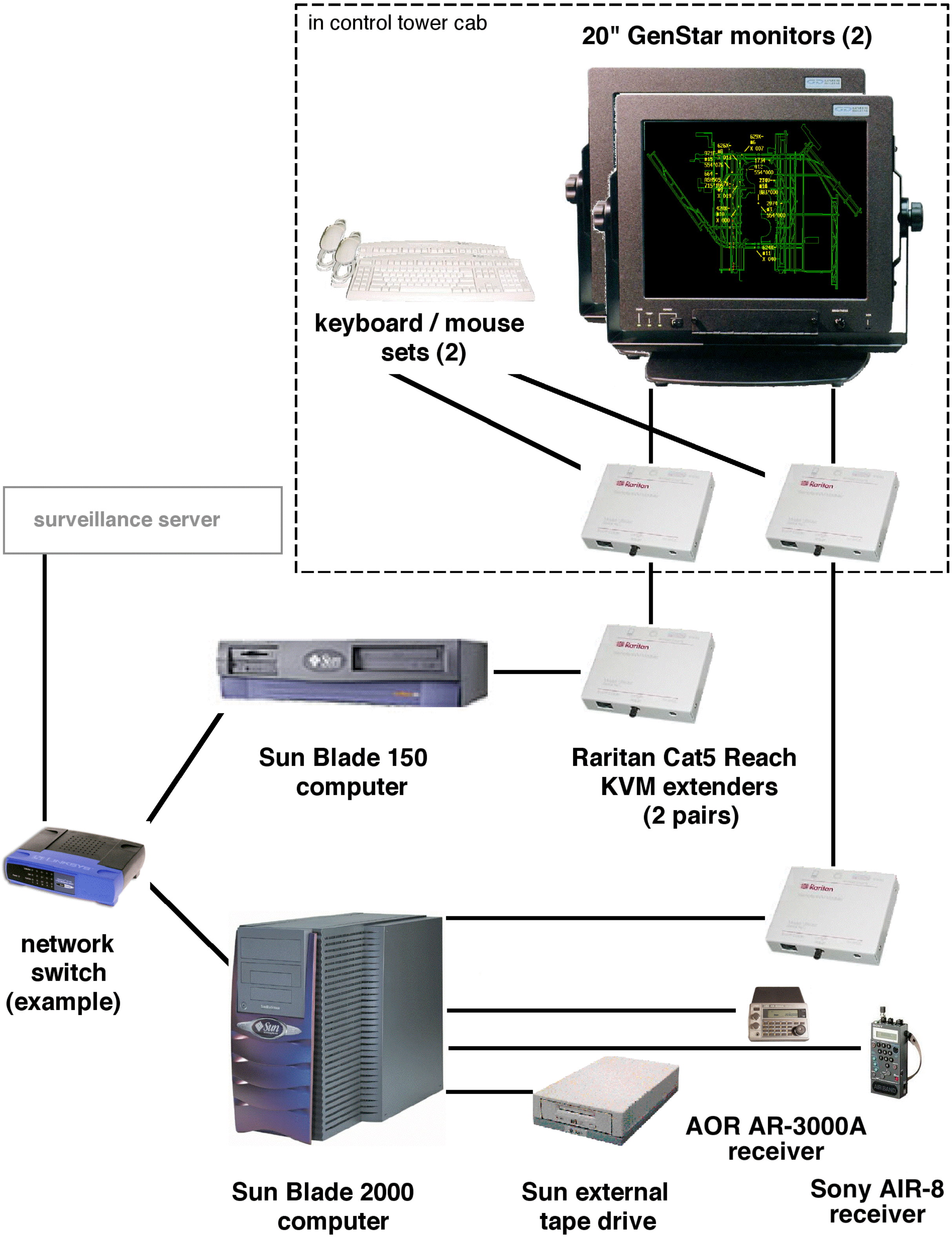

Figure 10. Hardware installed at the DFW Center Tower for shadow operations and maintained for operational evaluation.

7 Training

A successful evaluation of RWSL depends on the thorough training, knowledge, and commitment of three categories of users: controllers, pilots and vehicle operators. In order to accomplish the required training, MIT/LL employed a "train the trainer" concept. The MIT/LL team worked with the FAA to develop training materials to support the outcomes outlined for the three categories of users described above. FAA personnel received training that met the requirements of DFW Air Traffic management.

The following sections provide an overview of the training.

7.1 West Tower Training

Operational controllers in the west tower had a passive role in the evaluation. When the RWSL system operated in accordance with its design requirements, the RWSL operations from the tower proved to be seamless with no noticeable effects unless a potential incident occurred. Notwithstanding this passive role, all 50 DFW controllers were required to be familiar with the operational concept. They were also required to be prepared to respond to the possibility of pilots questioning clearances when RWSL indicates an unsafe condition, as well as when the system appears to deviate from normal operation. Controller training was completed 11 February 2005, except for one controller who was trained later on return to the facility.

Air traffic controller supervisors were trained to make the necessary keyboard or trackpad entries on the RWSL lighting control remote display to accommodate changes in traffic flows, rain condition, and light intensities. They were also trained to disable the RWSL system by going to an off configuration (soft kill) or by shutting off the current to the light fixtures (hard kill). In the event that a controller supervisor or test administrator was not present or available during any portion of the RWSL evaluation, the RELs were disabled and the ATIS updated to reflect this situation. At no time were the RELs intentionally operated when a controller-in-charge (CIC) was responsible for the shift conduct. Supervisor training was completed 11 January 2005.

7.2 Pilot Training

Pilots and vehicle operators were required to have an awareness of the operational concept. All participating pilots needed to understand that a red illuminated light indicates that the runway is unsafe for entry or crossing at that location. They needed to understand that RWSL information does not constitute a clearance; specifically that the absence of a red illuminated light does not indicate permission to proceed. They needed to be alert to the fact that during the operational evaluation not all intersections will have runway status lights and the system may not be operational 24/7.

In general, pilots received their training through company channels using materials developed at Lincoln. This was supplemented by various means including an Internet website RWSL.net, articles in various pilot and aviation magazines, presentations at pilot and industry conferences, NOTAMs, ATIS broadcasts, Jeppesen inserts (60-8 and 60-8a pages), pilot bulletins, a letter to airmen, CD-ROMs, posters, and scripted animations and recorded data movies. Materials were delivered to over 70 contacts in all. To aid others to write articles about RWSL, a Backgrounder document was written by MIT/LL and the FAA. American and Eagle managers and FAA pilots were briefed at their safety meeting. One airline (AAL) added RWSL to their recurrent training for all DFW pilots. Lincoln also coordinated with airline pilots unions throughout the operational evaluation. Training materials were delivered to the airlines on 28 October 2004 (AAL and EGF) and 19 January 2005 (others).

Lincoln held several demonstrations of the RWSL Operational Concept and recorded data from DFW Shadow Operations with RELs on screen at such venues as the ALPA Annual Safety Forum, 2004 and 2005, the National Business Aviation Association, 2004, and the FAA Airventure at Oshkosh, 2004. RWSL articles were published in the Airline Pilot (ALPA magazine) in March and August 2005, the ATCA Bulletin, January 2005, and the American Airlines Flight Bulletin. APA and ALPA sent email reminders to pilots to direct them to pilot training materials and to solicit feedback via the RWSL website.

7.3 Vehicle Operator Training

Vehicle operators received their training in accordance with standard airport operations practices. All individuals approved to operate vehicles on the airside at DFW were trained by the DFW airport authority using online training materials provided by Lincoln. Vehicle operator training was completed on 14 February 2005.

8 Pre-test Activities

8.1 Local Optimization

Prior to the operational evaluation, Lincoln with the support of the controller supervisor team fine-tuned the optimization of the system at DFW. This allowed the system to be tuned on an intersection-by-intersection basis to accommodate local operational procedures, including the use of anticipated separation, by minimizing interference. In particular, it allowed retuning the system to account for any delays incurred by the field lighting system and to accommodate changes made after shadow operations tests.

Lincoln, with the support of the controller supervisor team, identified anomalies at each intersection via the RWSL test display located in the center tower, in conjunction with viewing the actual traffic from the tower cab. They conveyed to the MIT/LL personnel the nature of the adjustment needed to minimize interference at each intersection, and evaluated the adequacy of the adjustment made, as reflected in subsequent instances of interference at each intersection (i.e., the need for additional adjustment, if any). Recorded scenarios were also used as needed for optimization.

8.2 FLS Integration and Phased Turn-On

A series of tests was conducted to ensure that the FLS was properly installed and configured, that RWSL-FLS communication worked, and that the FLS satisfied operational and performance requirements. Three integration test phases were completed: an FLS site acceptance test, an

RWSL/FLS integration test, and an operational characteristics test. Detailed plans for integrating the FLS with the rest of RWSL are given in the RWSL pre-OpEval test plan [8].

8.3 RWSL Flight Tests

Two flight tests were conducted at DFW on 15–16 and 29 January 2005. These determined that RELs are visible to airplane crews and are not distracting during takeoff or landing operations on the same or a parallel runway. Some anomalies were detected during the first flight test, requiring RWSL re-engineering. These anomalies included a RWSL-FLS communications error that caused a stuck light and some undesirable behavior for go-around and takeoff abort operations. RWSL was modified to correct the detected anomalies and subjected to the second flight test.

8.4 Test Readiness Review

A test readiness review was conducted after the local optimization and integration and prior to commencement of operational evaluation. This review verified that the system was ready for test. The RPMT and all interested parties were invited to participate in the test readiness review. A detailed test readiness review checklist was prepared for review by interested parties.

9 Test Activities

9.1 Technical Support

The RWSL test team ensured that the RWSL hardware was in its test configuration, was operating correctly, and was ready for testing. The RWSL test team also verified that any ancillary equipment such as radio receivers was properly configured. The RWSL test team ensured that the recorded data was archived for analysis.

Basic system operation required that a RWSL test team member or supervisor open the laptop lid, log in with a password, enter a menu command to start the system display, run the test, close the display, and close the laptop computer lid. Technical support for the test was provided locally or remotely from the MIT/LL site.

In addition to basic system operation, the RWSL test team members and supervisors were also responsible for entering time-stamped log and commentary data during the test sessions. An automated script periodically backed up technical performance data to removable media and shipped the data back to Lincoln Laboratory for analysis. A basic system monitoring capability was also built that allowed remote supervision of the RWSL software.

9.2 Test Administrator

The test administrator entered the runway configuration, rain condition, and light intensity into the RWSL lighting control display as needed when conditions change during the course of operational evaluation. The test administrator was assigned by MIT/LL on a daily basis.

9.3 Air Traffic Controller Supervisor Participation

The supervisor coordinated the entry of RWSL status into the ATIS message. The tower supervisor also acted as liaison between the test team and tower personnel. After an initial period, the supervisors took on the role of test administrator.

During the first two weeks of operational evaluation, and again during the last two weeks, controller supervisors filled out questionnaires to determine their initial and overall opinions concerning RWSL operations.

9.4 Air Traffic Controller Participation

During the first two weeks of operational evaluation, and again during the last two weeks, controllers were provided with the opportunity to voluntarily complete questionnaires to determine their initial and overall opinions concerning RWSL operations. Controllers were provided a means to record comments on individual operations at their option. The content of the written questionnaires and interview questions were coordinated in advance with NATCA and DFW air traffic management for information and approval. The questionnaires included a limited number of key questions. The controllers were encouraged to voluntarily talk informally during verbal debriefs as available to provide supporting anecdotal evidence to the written responses. All controller written and verbal responses were documented by the test administrator as appropriate. All written responses were destroyed in order to ensure individual controller anonymity and privacy.

9.5 Pilot and Vehicle Operator Participation

Since the runway status lights were shown on a continuing basis during the operational evaluation test periods, a large representation of pilots who frequent DFW participated in the evaluation. Pilots were asked, through their airline company office or through the FBO, to provide responses to a questionnaire, available either in written form or online on the RWSL website. Vehicle operators were also asked, via the airport authority, to provide questionnaire responses in a similar fashion.

9.6 Other Observer Participation

In addition to the active participants, a cross-section of interested parties and stakeholders were invited to the operational evaluation. Such groups included FAA headquarters and regional office management, DFW airport management, airline representatives, and pilot union representatives. They were most readily accommodated as observers in the center tower, but after prior coordination with the DFW facility manager some were admitted to the west tower for observation.

9.7 Test Duration

The operational evaluation was three months in duration. RWSL operation was intended to operate initially on a part-time basis, but in fact always operated on a full-time basis, limited to those times when a supervisor was on duty.

10 Data Collection

The operational evaluation provided two different categories of data, each with its own data collection methods. Technical data were recorded automatically during test periods for later offline analysis. Operational feedback was elicited from pilots, vehicle operators, controllers, and other personnel for subsequent evaluation. These will be described in the next subsections. Analysis and assessment methods will be described in the following section.

10.1 Technical Data

All RWSL system input and output data were recorded during tests. These data include surveillance system inputs to RWSL and light commands produced by RWSL. Safety logic internal data were also recorded to facilitate subsequent technical performance analysis. All data were time-tagged to allow replaying and post-processing the data for analysis. In addition, a time-tagged text logging facility was used to annotate the tests. This was used to record wind and weather information, operational and technical observations, and any other text-based information as needed. All adaptation data used in the test were recorded with the test data for configuration control.

10.2 Operational Feedback

The operational feedback resulting from the conduct of the operational evaluation included initial feedback of impacts to system capacity, controller supervisor and pilot communications, and pilot and vehicle driver situational awareness. Elicited observer feedback included suggestions for system tuning and safety enhancement. The pilots were asked to answer survey questions to assess the operational suitability, safety, and effectiveness of the runway status lights. All user feedback was anonymized to protect individual privacy.

Voice transmissions between air traffic controllers and pilots and vehicle drivers over the local and ground frequencies were recorded for confidential post hoc analyses. As the analysis is complete, the recordings will be destroyed on direction from the FAA. Recorded data will not be used to implicate a controller, pilot, or vehicle operator in a runway incursion or runway safety violation or incident.

11 Technical Data Analysis

11.1 Operational Environment

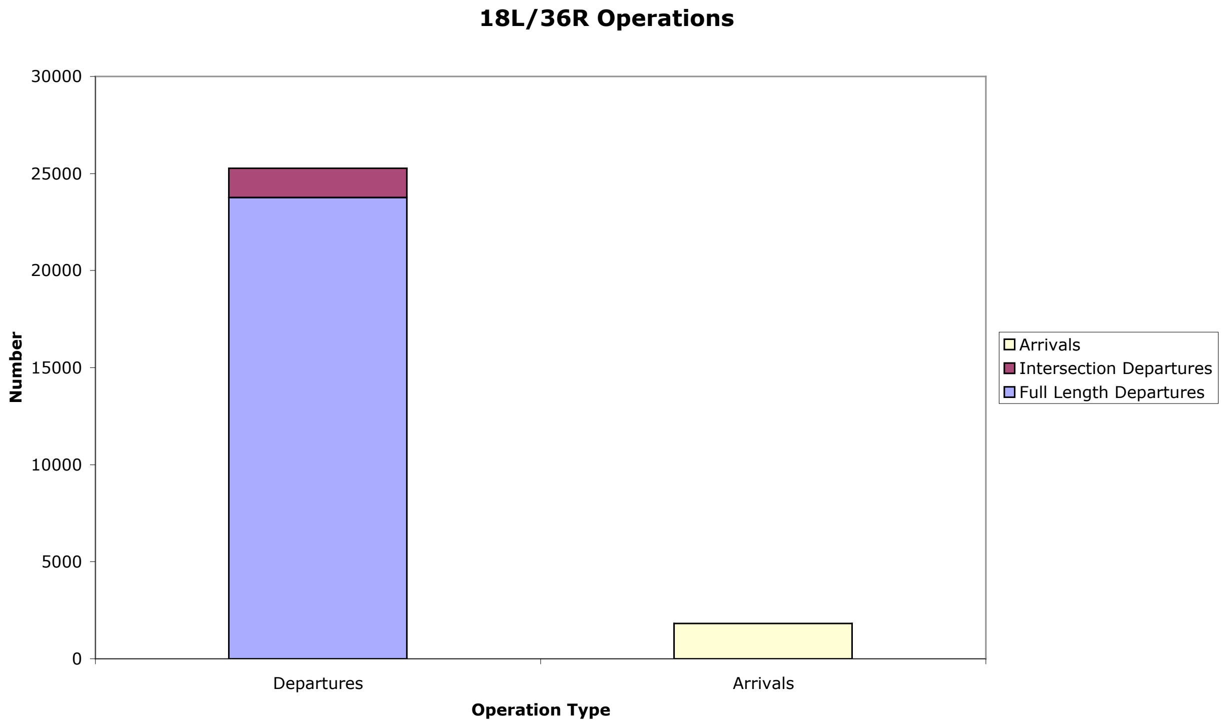

Figure 11. 18L/36R operations.

About 93% of the operations on 18L/36R during the operation were departures. About 87.7% were full-length departures, and 5.5% were intersection departures. Only 6.7% of the operations were arrivals.

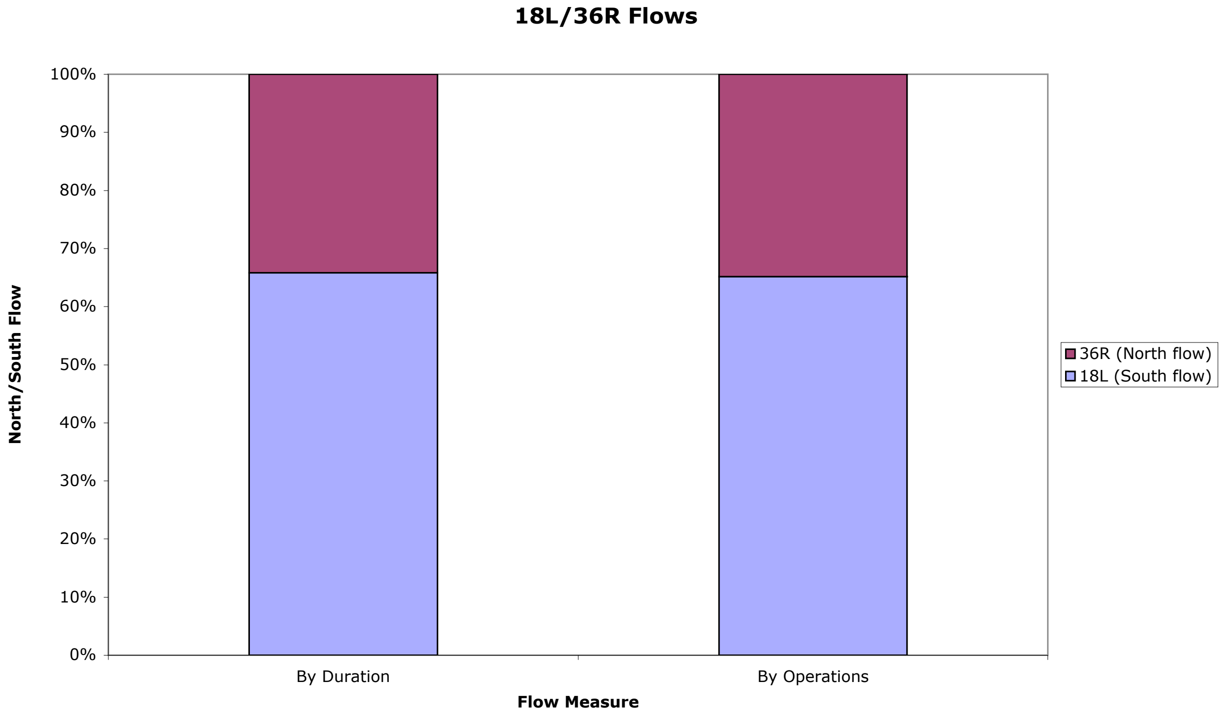

Figure 12. Runway configuration according to duration or number of operations.

About 65% of the operational evaluation was in south flow (runway 18L). This was true when measured by duration or by number of operations. The remaining 35% was in north flow (runway 36R).

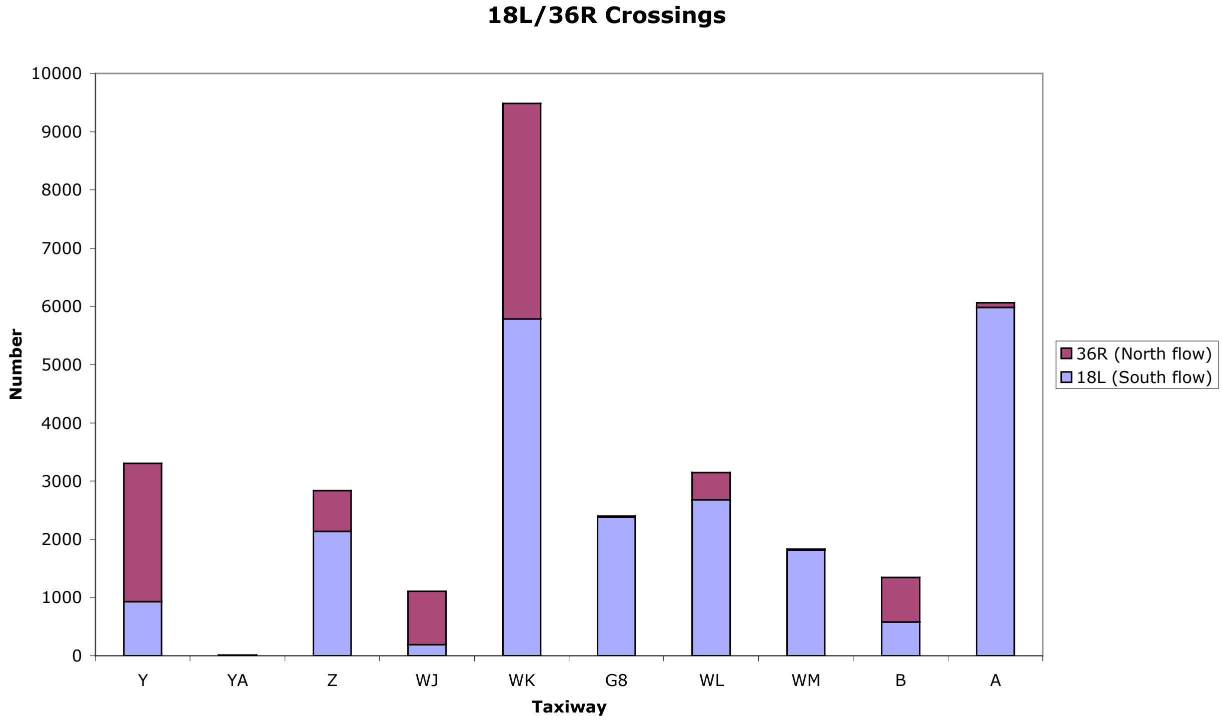

Figure 13. Number of 18L/36R runway crossings at instrumented taxiways.

Every runway crossing at an instrumented taxiway (those equipped with RELs) was counted during the operational evaluation. The most common crossing points were WK and A, followed by Y, WL, and Z. In south flow (runway 18L), the most common crossing points were A and WK, while in north flow (runway 36R), the most common crossing points were WK and Y.

11.2 Technical System Operation

11.2.1 Lighting System Utilization

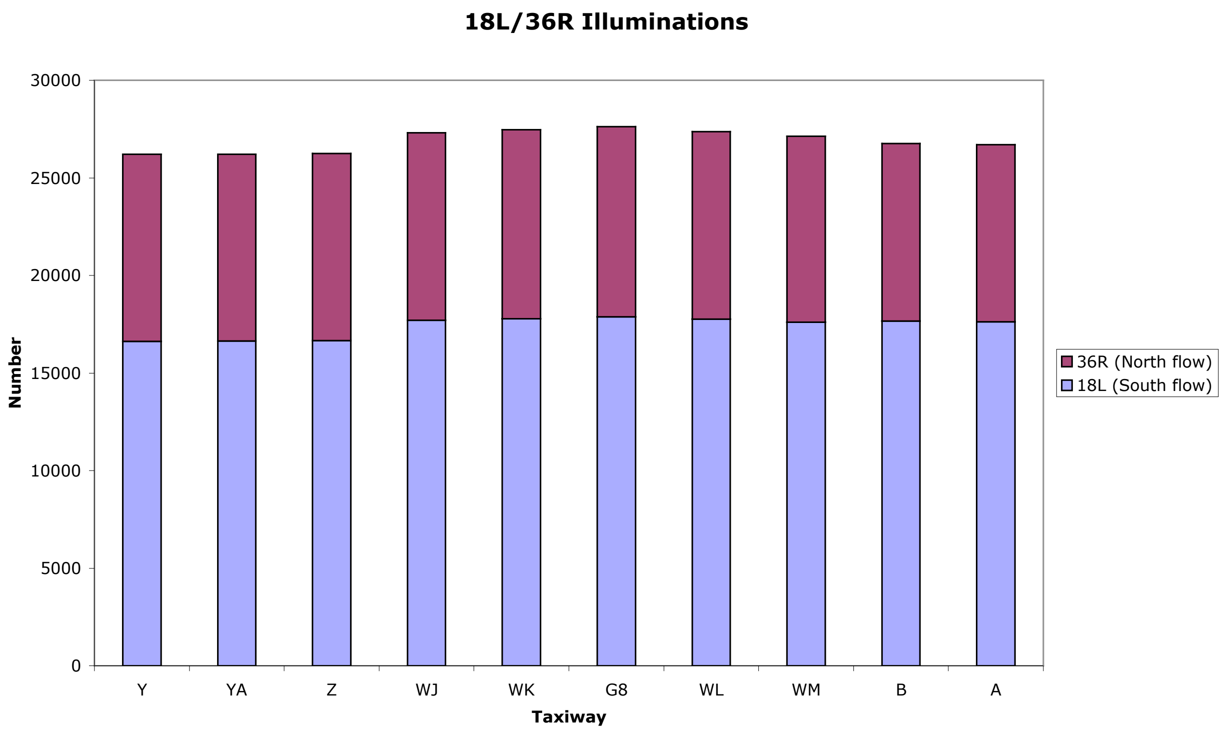

Figure 14. Number of illuminations at each instrumented taxiway.

Because all RELs forward of a departure or an arrival are illuminated, and because most departures are full-length departures, most RELs are used for every operation. Thus the number of illuminations is nearly constant across instrumented taxiways. There is a slight increase towards the center of the runway. This has two causes. First, some departures are intersection departures, which tends to reduce the number of illuminations at Y, YA, and Z in south flow and A and B in north flow. Second, sometimes aircraft in landing rollout state cause some lights to reilluminate, typically near their exit point near the center of the runway.

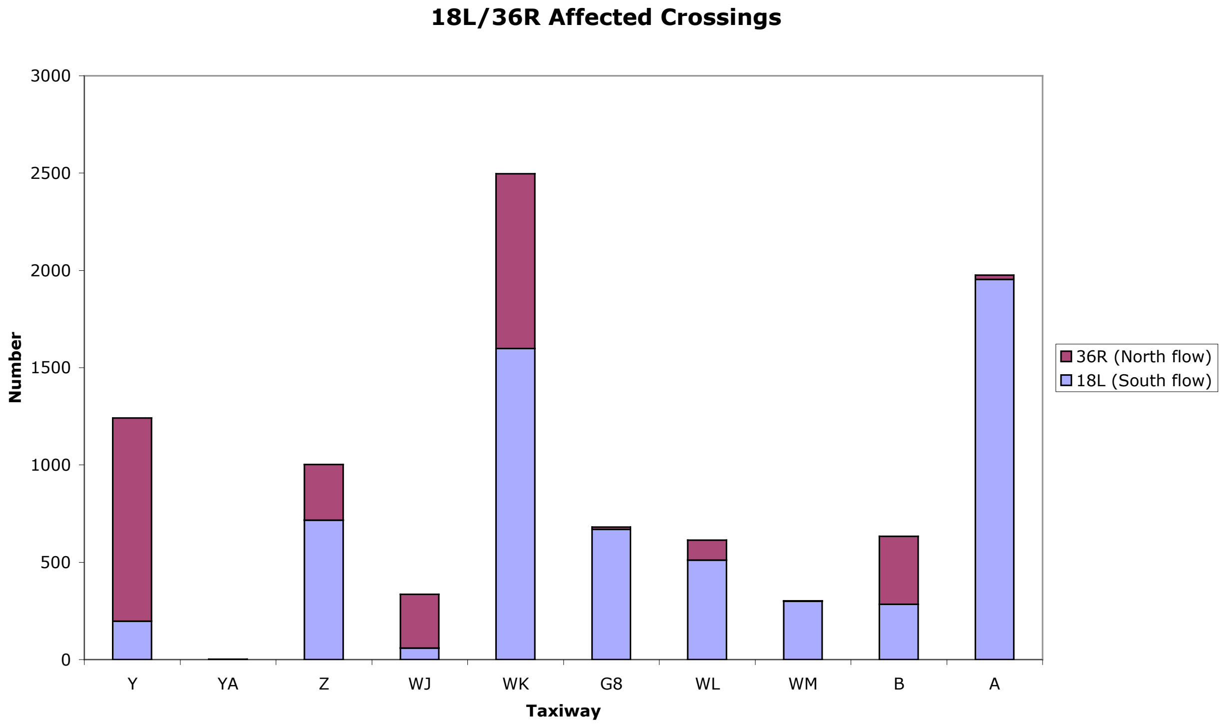

Figure 15. Number of crossing aircraft affected by runway entrance lights.

An aircraft or vehicle is considered to be affected by runway entrance lights if it is at the taxiway near the lights while the RELs are illuminated and subsequently crosses the runway at that location. Affected crossings represent those that potentially benefit from REL operation. About 30% of all runway crossings are affected crossings. The distribution of affected crossings nearly matches that of crossings in general. There are some differences, however. In south flow, crossings at B were proportionately more likely to be affected by REL operation, while those at Y, WL, and WM were less likely to be so affected. In north flow, crossings at G8 (though few in number), B, Y, and Z were more likely to be affected by REL operation, while those at WM were less likely to be so affected.

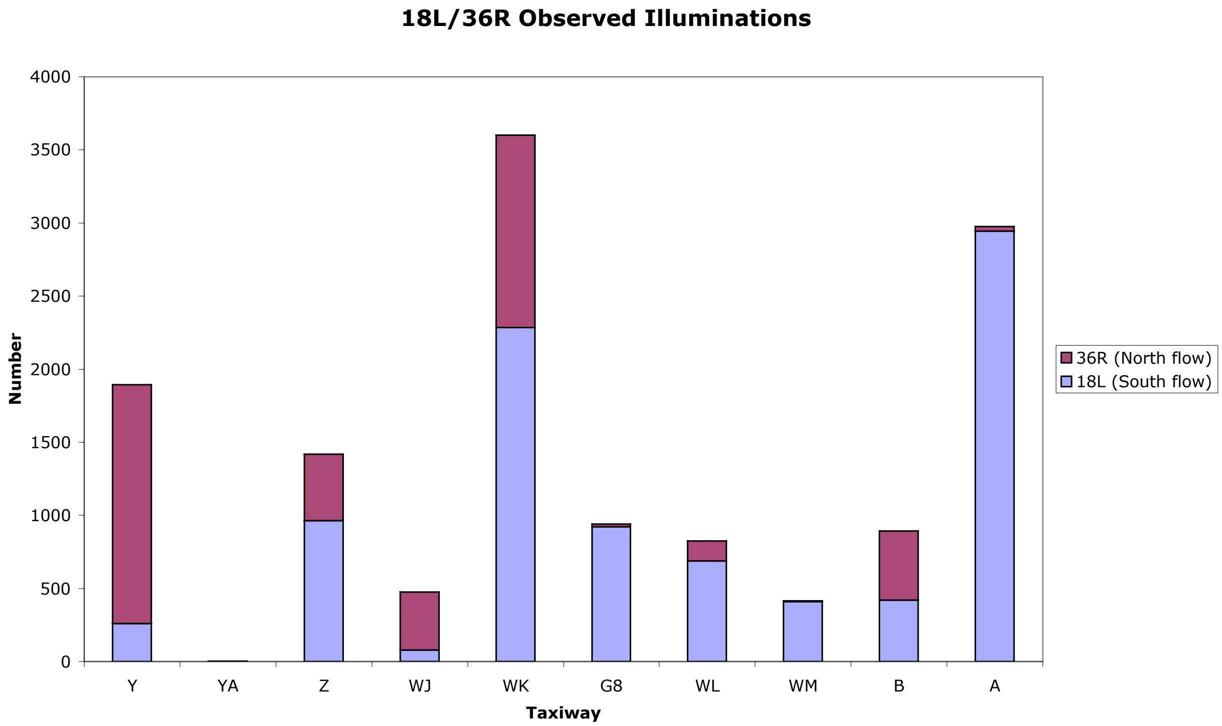

Figure 16. Number of observed illuminations.

An observed illumination is an illumination with an aircraft or vehicle in a position to observe it. These differ in number from the affected crossings because a single aircraft can observe illuminated RELs more than once before crossing the runway. The distribution of observed illuminations follows closely that of affected crossings.

11.2.2 Lighting System Intensity Usage

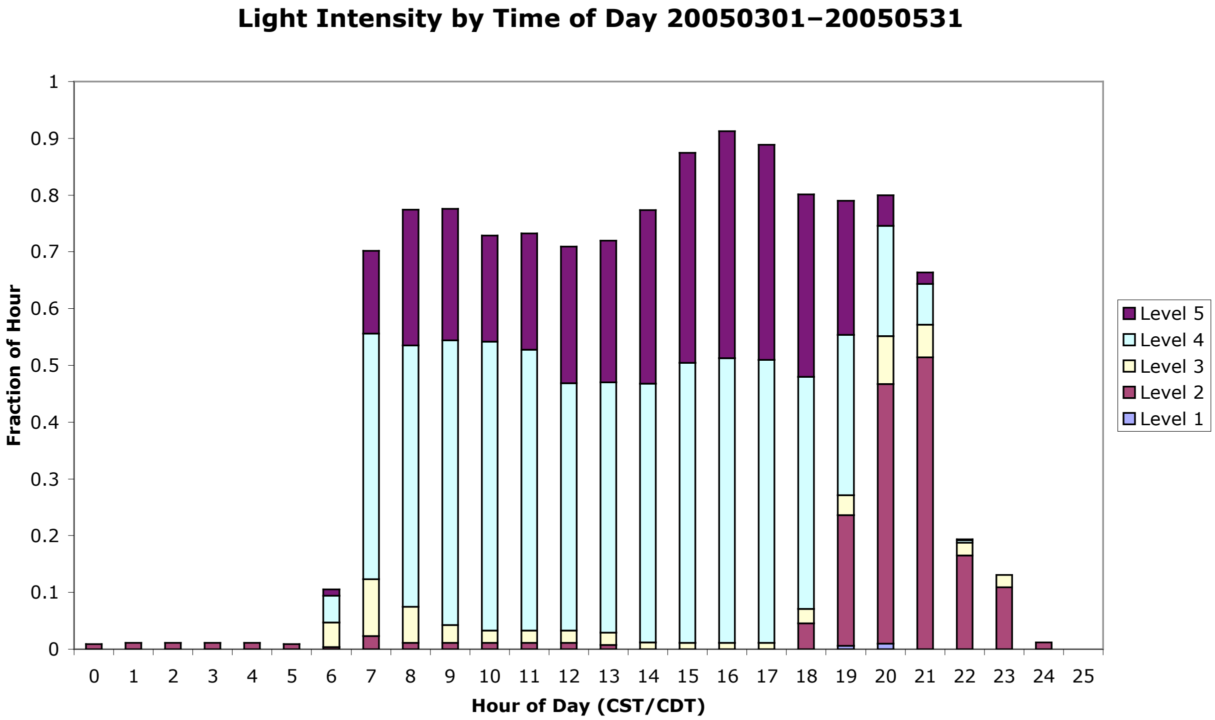

Figure 17. Light illumination level by time of day.

The operational evaluation was designed to be limited to the periods when a supervisor was in the West control tower (as opposed to a controller-in-charge or CIC). Because of this, the utilization times were largely limited to 7AM to 10PM. One night, the system was purposely left on through the night to test nighttime procedures. During most of the operational evaluation, light current level 4 was in use during the day and level 2 at night, with level 3 used during dawn and dusk periods. In the course of the evaluation, pilot feedback indicated that level 5 and level 3 were more appropriate for use during day and night, respectively, to make the RELs more distinctly visible and representative of a warning system. Thus there was some usage of these higher light current levels in the appropriate periods, as shown in Figure 17.

The frequency of level 5 usage with respect to level 4 usage varied through the operational evaluation period. Initially, level 4 was used during the daytime nearly to the exclusion of level 5. After the pilot feedback was evaluated and direction given to the supervisors to use level 5 during daytime, its use increased. Towards the end of the operational evaluation, however, the utilization rate of level 5 did decrease noticeably, as shown in Figure 18. Because of this, in advance of the extended operational evaluation that commenced on 17 June 2005, supervisors were instructed that level 5 was to be the normal current level used during daytime.

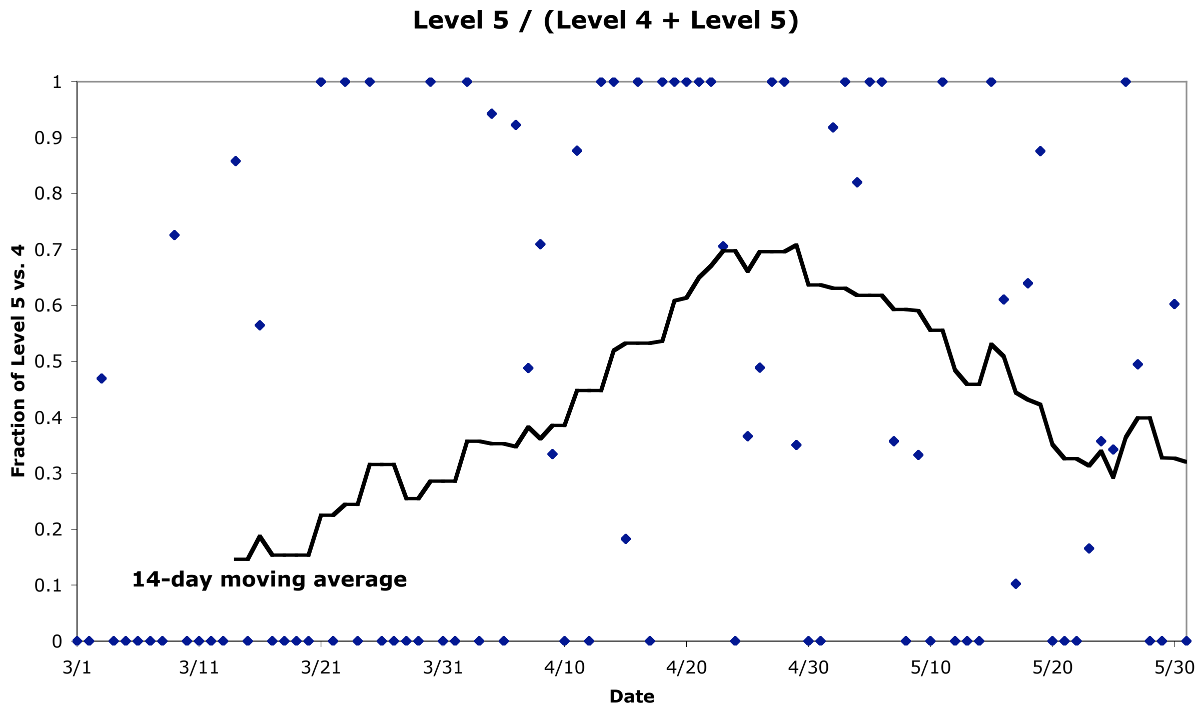

Figure 18. Relative frequency of level 5 illumination in comparison with level 4, shown with a 14-day moving average.

11.3 Technical System Performance Assessment

The purpose of the technical system performance assessment was to measure the correctness of light operation and impact on controller-pilot communications. Three light metrics were used: missed detections (MDs), false activations (FAs), and instances of interference (I). A two-step process was used to produce these metrics. An additional measure was used for communications: the light-induced communications metric.

Automated analysis software was run using the recorded data and adaptation data as inputs. The result of the performance analysis software is a set of tables with precise information about each arrival and departure and the corresponding timing performance of the runway-entrance lights. Preliminary identification of candidate anomalies (missed detection, false activation, and interference events, or MDs, FAs, and Is) was performed automatically by the performance analysis software. The output of the performance analysis software was then reviewed manually. Events of interest were replayed and the display used to assess each candidate anomaly, to verify the automatic assessment output. Additional events identified by the test participants during the operational evaluation and by test team members during data playback were also analyzed for light anomalies and light-induced communications events. The numbers of verified light anomalies of each type and of light-induced communications events were tallied and ratioed as specified.

11.3.1 Anomaly Causes

The identified anomaly causes were placed into one of the following eighteen categories:

11.3.1.1 100' encoding wrong threshold

For departures, the RELs need to be turned off when the aircraft is off the ground and has a positive rate of climb. To accomplish this using the altimeter data provided in the Mode C responses from the aircraft transponder, it is necessary to account for the different levels of accuracy available from different transponders. Most aircraft operating at DFW have 25' encoding, meaning the minimum altitude step that can be transmitted by the transponder is 25'. Some light aircraft have 100' encoding transponders. A larger altitude threshold is required for these aircraft to avoid the possibility that a least-significant-bit error could cause RWSL to declare the aircraft prematurely to be airborne. Unfortunately, the type of transponder, 25'- or 100' encoding, is not part of the transponder emission, so the ASDE-X does not include that information in its surveillance stream. RWSL compensates for this by determining the actual used resolution on the fly. When this algorithm errs, the wrong altitude threshold is used, and can cause the aircraft to be declared airborne early (if using the 25' encoding threshold incorrectly) or late (if using the 100' encoding threshold incorrectly).

Resolution of this problem requires an upgrade to RWSL.

11.3.1.2 AB adaptation error

DFW ATC asked that the distance parameter for turning on RELs for aircraft on arrival to 18L (not to 36R) be set separately for A and B to be 1/2 nmi, as opposed to the 3/4 nmi distance used at all other runway entrances and also for A and B in north flow. This change was requested because in south flow, sometimes controllers clear aircraft crossing at A and B with an aircraft less than 3/4 nmi out on final because these intersections are well downfield and due to the fairly long straight-in taxi route at these intersections. (In north flow, the corresponding intersections at Y and Z are not used as frequently for high-speed taxi operations, so a similar change was not required there.) This change was made, tested, and installed at DFW for both north and south flows, but not for mid-day flow changes. An adaptation error allowed the RELs at A and B to retain the 1/2 nmi distance inappropriately for aircraft on arrival to 36R, only after a mid-day runway configuration change from south to north flow. This adaptation error produced a large number of MDs because the RELs at A and B failed to illuminate until the arriving aircraft was at 1/2 nmi, about seven seconds after they should have illuminated. When the adaptation error was revealed by a configuration change on 7 March 2005, dozens of MDs occurred.

The adaptation was corrected on 8 March 2005. The affected day has been removed from the subset of data for good operation. Performance statistics for the full data set and the good data subset are reported separately.

11.3.1.3 Altitude offset bug

To produce AGL (above ground level) altitudes for aircraft, RWSL uses pressure altitudes uncorrected for the local barometric pressure and subtracts from them a moving average pressure altitude derived only from slowly moving aircraft (those presumably firmly on the ground). The algorithm that calculates the moving average allowed the offset to be corrupted by grossly incorrect Mode C altitude data. On 9 March 2005, such incorrect data was received from an aircraft, causing subsequent arrivals to 36R to be considered too high to be arriving to the runway, resulting in five MDs.

The altitude-offset condition resolved itself at the end of the day, and the algorithm was upgraded on 28 March 2005 to avoid this problem in the future.

11.3.1.4 ASDE-X ghost track

On 10 March 2005, faulty maintenance on the ASDE-X to repair a receive unit (RU) resulted in a combination of RU wiring errors. This resulted in the ASDE-X target processor (TP) using the time-of-arrival data for one RU thinking it was for another. When either of the miswired RUs was included in a multilateration solution, that solution was grossly incorrect. This caused ghost tracks in incorrect positions and trajectories, while the real aircraft was often not under track. The typical case was an arrival actually to 36L causing a ghost track apparently on a skewed arrival to 36R, causing REL FAs and sometimes I anomalies.

The ASDE-X RU miswiring was corrected in the late afternoon of 23 March 2005. Because this surveillance system problem persisted so long and created so many anomalies, the corresponding days have been removed from the subset of the data for good operation. Performance statistics for the full data set and the good data subset are reported separately.

11.3.1.5 ASDE-X heading glitch

RWSL uses the heading derived from the velocity estimated by the ASDE-X when available. Sometimes, the ASDE-X produces velocities that are not compatible with the true aircraft motion. This can happen on or shortly after ASDE-X track initiation or during periods of high acceleration or deceleration, or when or after a poor multilateration solution is used by ASDE-X. This can cause a MD if the erroneous heading would be such that an REL would turn off, for example, by being outside the acceptance angle for a runway for departure declaration. It can also produce a FA, though this was not noted during the operational evaluation.

Resolving this problem will require an upgrade to the ASDE-X.

11.3.1.6 ASDE-X MLAT track gap

The ASDE-X occasionally has multilateration tracks with poor probability of detection. This results in a gap in the surveillance for an aircraft, which can cause an REL MD. It is also possible that a track gap will cause a FA because the lack of track updates keeps a light on too long. A FA due to an ASDE-X track gap was not seen during the operational evaluation, however.

Resolving this problem will require an upgrade to the ASDE-X.

11.3.1.7 ASDE-X no MLAT

The ASDE-X sometimes wholly fails to establish a multilateration track for an aircraft, even though the aircraft's transponder is functioning. For departures, this usually is relatively unimportant because of the availability of ASDE-3/Primagraphics radar tracks. For arrivals, however, it is important because there is a gap between the ASR surveillance, which still works in this condition, and the ASDE-3 surveillance, which also still works. Typically the lack of ASDE-X MLAT data causes an MD, but if the arriving aircraft has already illuminated RELs due to ASR data prior to leaving ASR coverage, then the RELs can remain illuminated incorrectly until the ASR track is dropped by the ASD-X, causing an FA or I.

Resolving this problem required an upgrade to the ASDE-X. An upgrade to the ASDE-X/ASR interface was performed on 2 August 2005, and preliminary analysis indicates that the ASDE-X no MLAT problem has been greatly reduced. Apparently the ASDE-X fusion process was suppressing certain MLAT tracks when the corresponding ASR data was unavailable or unreliable.

11.3.1.8 ASDE-X split track

The ASDE-X sometimes produces two tracks for the same aircraft. Commonly one is based on Mode S (squitter) transmissions and the other on Mode A (4096 code) or Mode C (altitude) transmissions, but this is not always the case. Often when there are two tracks, one of them behaves poorly: it has a low or inconsistent update rate, or the surveillance is not as accurate. It is possible that the split track could interfere with the Lincoln fusion algorithm if there is an ASDE-3/Primagraphics track, but this was not a significant problem. Usually a split track causes RWSL anomalies only if one of the tracks has large track gaps, where it can produce FAs.

Resolving this problem will require an upgrade to the ASDE-X.

11.3.1.9 ASDE-X velocity glitch

This problem is similar to the ASDE-X heading glitch problem discussed in Section 11.3.1.5. RWSL uses the velocity estimated by the ASDE-X as its velocity estimate when available. Sometimes, the ASDE-X produces velocities that are not compatible with the true aircraft motion. This can happen on or shortly after ASDE-X track initiation or during periods of high acceleration or deceleration, or when or after a poor multilateration solution is used by ASDE-X. This can cause a MD if the erroneous velocity would be such that an REL would turn off, for example, by anticipated separation. It can also produce a FA, most notably by a false departure declaration, though this was not noted during the operational evaluation.

Resolving this problem will require an upgrade to the ASDE-X.

11.3.1.10 Fast ground bit

RWSL uses the ground bit emitted by Mode S transponders as part of their squitters. The ground bit is supposed to indicate whether the aircraft is on the ground, and was designed to allow TCAS to interrogate only airborne aircraft to reduce spectrum utilization. The ground bit is typically controlled by a squat switch in the nosegear, and thus indicates off-ground when a departing aircraft is rotating, just prior to becoming airborne. If the ground bit indicates off-ground too soon in the departure roll, well before the aircraft is in fact airborne, then RWSL can turn off the RELs too soon.

A solution to this problem has been designed, implemented, tested on recorded data, and will be tested during the upcoming DFW THL shadow operations tests. This solution, called the integrated altitude – ground bit algorithm, involves an upgrade to the RWSL airborne declaration algorithm, integrating the altitude-based method and the ground bit method for airborne declaration.

11.3.1.11 Fast taxi into position

It is possible for an aircraft to taxi into position for departure faster than the departure velocity threshold, especially if the departure velocity threshold is low. If this occurs when the aircraft is lined up with the runway, the RELs will turn on. If the pilot intent (as witnessed by the future actual aircraft motion or by the actual clearance) is to come to a stop on the runway, then the REL illumination is a FA. This occurred once during the operational evaluation, when the departure velocity threshold was set to 25 kt.

Resolving this problem will require an upgrade to RWSL.

11.3.1.12 Fast taxi on runway

Aircraft taxi on the runway, typically when the airport is changing configurations or when the aircraft had taxied onto the runway for departure but was unable to execute the departure. When an aircraft taxis on the runway faster than the departure velocity threshold, it will be identified as a departure and the RELs will illuminate, representing a FA. If this illumination interferes with a crossing clearance or operation, then the anomaly is considered an interference.

A technical solution to the fast taxi on runway, the taxi-on-runway (TOR) state, is discussed in Section 11.4

11.3.1.13 No altitude

Altitude information is not always available for all departures. Sometimes an aircraft takes off without its transponder turned on or with it set not to reply to Mode C interrogation. When altitude information is not available for a departure, the velocity profile algorithm is the only one available for airborne declaration, and it is somewhat less reliable than the algorithm that uses altitude. This can result in airborne declarations that are too early or too late, resulting in MDs or FAs, respectively, though FAs are more typical.

Resolving this problem requires improving the velocity profile algorithm for airborne declaration, or augmenting pilot or controller-pilot procedures to make transponder operation more reliable during departures.

11.3.1.14 Operational incompatibility

RWSL is designed and tuned to be compatible with almost all normal airport operations. Occasionally, however, an operation occurs whose execution is too tight for the time or distance parameters used in RWSL, and this results in interference with an otherwise safe operation. This occurred once when a crossing clearance was given at an intersection in front of a previous lander, when the lander had not yet slowed to the landing rollout (LRO) state. The remaining cases occurred when an aircraft was instructed to cross a runway with another aircraft on short final to that runway, with the clearance given or the crossing undertaken when the arrival was inside the 3/4 nmi distance for the RELs to turn on. A superset of these anomalies is discussed in Section 11.4.

Resolving this problem would require tuning RWSL, which would result in a loss of effectiveness, or avoiding the sometimes tight clearances given by controllers at a busy airport.

11.3.1.15 Rain in normal mode

Rain can cause the ASDE-3/Primagraphics surveillance to include large numbers of moving rain clutter tracks. The normal operating procedure for RWSL is to switch it to limited mode when AMASS is in limited mode. In RWSL, this causes the ASDE-3/Primagraphics track data to be ignored. When limited mode is not engaged during significant rain, RELs can turn on inappropriately, resulting in FAs and Is.

A method to reduce the probability of this occurring is to allow the RWSL system to switch to limited mode automatically when it detects significant numbers of false ASDE-3/Primagraphics tracks. An algorithm to accomplish this has been designed, implemented, and tested in the lab, and will be tested on a weather-available bases during the THL shadow operations tests at DFW in September.

11.3.1.16 Sticky ground bit

This anomaly cause is the opposite of the fast ground bit (see Section 11.3.1.10). When the ground bit transitions to off-ground very late or not at all for a departure, the RELs could stay on too long, causing a FA, or, if it interferes with an otherwise safe crossing, interference.

The solution to this problem, the integrated altitude – ground bit algorithm, is described in Section 11.3.1.10.

11.3.1.17 Transponder off

An aircraft operating with its transponder off can only be seen by RWSL in primary radar surveillance from the ASDE-3/Primagraphics system. The problem could also be mimicked by a fault in the ASDE-X resulting in loss of track, and thus be equivalent to the ASDE-X no MLAT cause. In either case, no altitude information is available, and, for arrivals, no surveillance is available at all until the aircraft descends below about 200 ft AGL within the airport runway/taxiway environment. This can result in a missed detection, false activation, or interference due to an erroneous airborne declaration based on velocity only, or in principle due to RELs being left off for an arrival invisible until after it crosses the runway threshold. The latter possible anomaly was not seen during the operational evaluation, however.

Resolving this problem will require better compliance with transponder operating procedures at DFW, or an upgrade to the ASDE-X if the problem is determined to have its origin there.

11.3.1.18 Transponder off – limited mode

An aircraft operating with its transponder off when the RWSL is set to limited mode (as during a rainstorm) is totally invisible to RWSL. This results in MDs.

Resolving this problem will require better compliance with transponder operating procedures at DFW, or an upgrade to the ASDE-X if the problem is determined to have its origin there.

11.3.2 Excluded data

Three days were wholly excluded from the operational evaluation period. On 4 and 5 May 2005, Siemens personnel performed maintenance work on the SMGCS system at DFW, which required them to disable the RWSL field lighting system. They did so without coordination and without adequately recording the times that RWSL field lighting system was disabled. Furthermore, the disabling of the field lighting system was done in a way that the RWSL central computer received no notification that the lights were not responding to commands. For this reason, these days were excluded from the operational evaluation. An additional day, 15 May 2005, was also excluded because the manual shutoff switch was shut off for the whole day.

Several other days were problematic for identifiable and eventually correctable reasons. The ASDE-X underwent faulty maintenance, resulting in miswired receive units (RUs), which greatly compromised surveillance in the period 10–23 March 2005. An RWSL adaptation error caused RELs at taxiways A and B to operate incorrectly for arrivals after a configuration change to north flow on 7 March 2005. Both of these errors

The most frequent anomaly cause was the ASDE-X ghost track, which was resolved during the operational evaluation. Another frequent anomaly cause, the AB adaptation error, was also detected and corrected during the operational evaluation. Because these two errors composed such a large number of the anomalies, because the ASDE-X wiring error also caused a significant number of other ASDE-X-related anomalies, most notably the ASDE-X no MLAT anomalies, and because these errors were limited in time, the periods during which these two causes were excluded to form a “good” data set, whose anomaly counts are shown in Table 2. The excluded periods are 7 March 2005 11:28AM to 9:38PM (AB adaptation error), and 10–23 March 2005 (ASDE-X wiring error).

11.3.3 Anomaly counts

The anomalies were classified according to identified cause and by anomaly type. Table 1 shows all the anomalies by cause and type that were found during the operational evaluation. A total of 201 anomalies of all types were detected.

	Type			
Cause	**MD**	**FA**	**I**	**Total**
100' encoding wrong threshold	6	2		8
AB adaptation error	24			24
Altitude offset bug	5			5
ASDE-X ghost track		29	10	39
ASDE-X heading glitch	1			1
ASDE-X MLAT track gap	1			1
ASDE-X no MLAT	27	5	2	34
ASDE-X split track		21	1	22
ASDE-X velocity glitch	2			2
Fast ground bit	17			17
Fast taxi into position		1		1
Fast taxi on runway			5	5
No altitude		3		3
Operational incompatibility			5	5
Rain in normal mode		2		2
Sticky ground bit		24	1	25
Transponder off	1	5		6
Transponder off - limited mode	1			1
Grand Total	**85**	**92**	**24**	**201**

Table 1. Anomalies according to cause and type.

The anomalies detected during the "good" period are shown in Table 2. A total of 114 anomalies of all types were detected. The dominant anomaly causes were sticky and fast ground bits, ASDE-X split track, and ASDE-X no MLAT. The secondary anomaly causes were 100' encoding wrong threshold, transponder off, and altitude offset bug.

	Type			
Cause	**MD**	**FA**	**I**	**Total**
100' encoding wrong threshold	6	2		8
AB adaptation error				
Altitude offset bug	5			5
ASDE-X ghost track		1		1
ASDE-X heading glitch				
ASDE-X MLAT track gap	1			1
ASDE-X no MLAT	12	4	2	18
ASDE-X split track		19	1	20
ASDE-X velocity glitch				
Fast ground bit	17			17
Fast taxi into position				
Fast taxi on runway			3	3
No altitude		3		3
Operational incompatibility			5	5
Rain in normal mode		2		2
Sticky ground bit		23	1	24
Transponder off	1	5		6
Transponder off - limited mode	1			1
Grand Total	**43**	**59**	**12**	**114**

Table 2. Anomalies during good operation, according to cause and type.

Not all of these anomalies were observed by aircraft or vehicles in a position to see the RELs on or off in error. The observed anomalies during good operation, numbering 32 in total, are shown in Table 3. The dominant causes of observed anomalies were sticky and fast ground bits and operational incompatibility.

	Type			
Cause	**MD**	**FA**	**I**	**Total**
100' encoding wrong threshold		1		1
AB adaptation error				
Altitude offset bug	2			2
ASDE-X ghost track				
ASDE-X heading glitch				
ASDE-X MLAT track gap				
ASDE-X no MLAT		1	2	3
ASDE-X split track		3	1	4
ASDE-X velocity glitch				
Fast ground bit	5			5
Fast taxi into position				
Fast taxi on runway			3	3
No altitude				
Operational incompatibility			5	5
Rain in normal mode				
Sticky ground bit		7	1	8
Transponder off	1			1
Transponder off - limited mode				
Grand Total	**8**	**12**	**12**	**32**

Table 3. Observed anomalies during good operation, according to cause and type.

Some of the anomalies were observed by multiple aircraft or vehicles in a position to see the RELs on or off in error. The anomaly observations during good operation, allowing for this possible multiplicity, numbering 37 in total, are shown in Table 4. The dominant causes of anomaly observations were sticky and fast ground bits, operational incompatibility, and ASDE-X split tracks.

	Type			
Cause	**MD**	**FA**	**I**	**Total**
100' encoding wrong threshold		1		1
AB adaptation error				
Altitude offset bug	2			2
ASDE-X ghost track				
ASDE-X heading glitch				
ASDE-X MLAT track gap				
ASDE-X no MLAT		2	2	4
ASDE-X split track		4	1	5
ASDE-X velocity glitch				
Fast ground bit	6			6
Fast taxi into position				
Fast taxi on runway			4	4
No altitude				
Operational incompatibility			5	5
Rain in normal mode				
Sticky ground bit		8	1	9
Transponder off	1			1
Transponder off - limited mode				
Grand Total	**9**	**15**	**13**	**37**

Table 4. Anomaly observations during good operation, according to cause and type.

The anomaly, observed anomaly, and anomaly observation counts should properly be normalized to the number of operations that took place on runway 18L/36R during the good data periods. When the rates thus obtained are expressed as their inverses, they can easily be compared with the operational goals as expressed by the RPMT shown in Table 5:

Phase	MD	FA	I	Total
Engineering Development	320	1600	800	200
Shadow Operations	360	1800	900	225
Operational Evaluation	400	2000	1000	250

Table 5. Performance goals for the RWSL RELs, expressed as inverse anomaly rates (operations per anomaly).

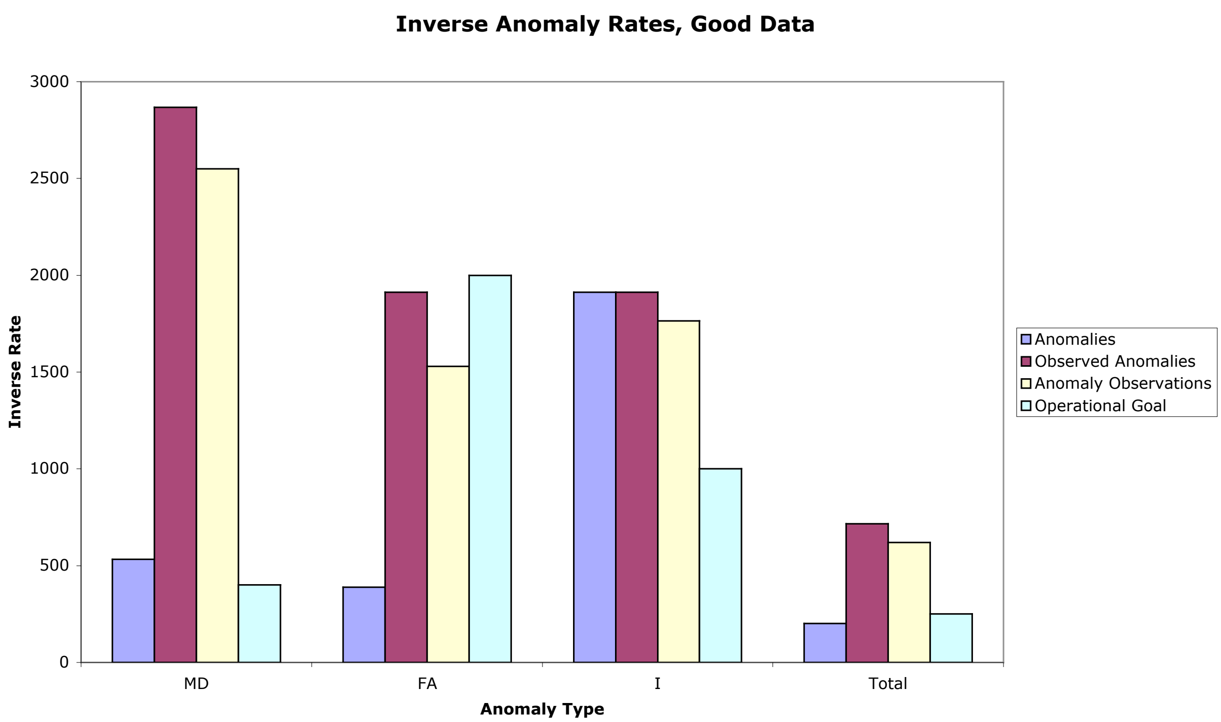

Figure 19. Inverse anomaly rates (larger is better) for good surveillance operation.

The resulting comparisons are shown in Figure 19. For the good data, the missed detection and interference performance goals were uniformly exceeded. The false activation goal was not achieved if all anomalies are counted. If only observed anomalies are counted, however, the false activation performance goal was very nearly achieved.

Nearly 40% of the false activations in the good data were caused by sticky ground bit, and nearly another third were caused by ASDE-X split tracks. If either of these two anomaly causes were eliminated, then the observed anomalies and the anomaly observations would achieve the false activation performance goals. If in addition to both these causes the ASDE-X no MLAT and the 100' altitude encoding bug were resolved, then the false activation performance goal would be entirely achieved according to all counting methods.

11.4 Light Busts

A light bust occurs when an aircraft or vehicle proceeds through an illuminated runway status light to cross the runway for runway entrance lights (RELs) or along the runway for takeoff hold lights (THLs). During the RWSL REL operational evaluation, there were 31,529 runway crossings in total. For these crossings, there were 29 incidents of light busts involving 39 aircraft crossing red lights, for a rate of about 1.2 light busts per 1,000 runway crossings. Light busts are important because they represent a safety hazard if the REL is on correctly or a false activation and interference if it is on incorrectly. Furthermore, light busts sometimes represent negative training, asking or allowing pilots to cross illuminated RELs when they should be trained not to do so. These light bust incidents were counted irrespective to duration; thus even anomalies shorter than 4 seconds are included in this summary. The light bust incidents were subjected to thorough causal analysis, and in most cases remedies were identified and implemented. The number of incidents and crossers for each cause is shown in Table 6.

The most common cause (by number of incidents) of the light busts was faulty surveillance caused by a miswiring in the ASDE-X, which created ghost tracks that caused light illuminations during normal and safe crossings. When this miswiring was corrected, that component of the light bust problem was fixed.

The most common cause (by number of crossers) of the light busts was aircraft taxiing on the runway being identified as departures. These taxiing aircraft cause light illuminations when controllers would normally be allowed to clear aircraft to cross the runway in front of the aircraft taxiing on the runway, resulting in light busts. For each aircraft taxiing on the runway, it is easily possible to have a number of crossers, and in fact there were an average of two crossers per incident. In one incident involving three crossers, the aircraft were told by the local controller to ignore the red lights. After that incident, controllers were reminded not to ask pilots to ignore red lights. The taxi-on-runway problem was ameliorated by increasing the taxi-to-departure transition speed from 20 to 25 knots on 5 May 2005. After that date, no further light busts due to aircraft taxiing on the runway were noted. (The transition speed was further increased to 30 knots after the operational evaluation period, but that obviously had no effect on the results reported here.)

Cause	Number of Incidents	Number of Crossers	Number told to Ignore Lights
Arrival inside 3/4 nmi	7	7	
ASDE-X ghost track	9	9	
Rain in normal mode	1	2	
Runway incursion	1	1	
Taxi on runway	7	15	3
Vehicle on runway	4	4	
Total	**29**	**38**	**3**

Table 6. Light bust causes and number of incidents and crossers, 1 March – 31 May 2005.

A related problem that is also a significant cause of light busts is caused by vehicles driving on the runway. RWSL prevents vehicles from entering the departure state and turning on RELs, but only if the vehicle is equipped with a transponder whose Mode S address is configured correctly in the vehicle table in ASDE-X. A non-equipped vehicle or one whose address is not configured in the ASDE-X will not be identified as a vehicle and will be allowed to enter the departure state when it exceeds the taxi-to-departure speed threshold, which is easily done by most vehicles. This problem was ameliorated when the transition speed was changed to 25 knots on 5 May 2005. After that date, no further light busts due to vehicles driving on the runway were noted. A summary of all light busts during the operational evaluation after 5 May 2005 is shown in Table 7.

Cause	Number of Incidents	Number of Crossers	Number told to Ignore Lights
Arrival inside 3/4 nmi	3	3	
ASDE-X ghost track			
Rain in normal mode			
Runway incursion			
Taxi on runway			
Vehicle on runway	2	2	
Total	**5**	**5**	**0**

Table 7. Light bust causes and number of incidents and crossers, 5 – 31 May 2005, after departure threshold change to 25 kt.

The taxi on runway problem and part of the vehicle on runway problem could be further addressed by redesign of the RWSL safety logic to incorporate a new state, Taxi On Runway (TOR). The purpose of the TOR state is to identify aircraft taxiing or vehicles driving on the runway with no intent to depart. RWSL would then not normally allow these aircraft or vehicles to enter the departure state, preventing the RELs from illuminating. The design of this state has been completed, but it has not yet been implemented in software or tested. Such an implementation is expected to address the taxi on runway and vehicle on runway incidents sufficiently well that the departure threshold can be returned to 25 kt without incurring any detrimental effects.

Another significant source of light busts was the occasional case of an aircraft crossing the runway with an arrival inside the 3/4 nmi distance required for the RELs to be turned on. Most of these cases were minor; the crossing was already well underway when the light turned on, and in one of the cases reported here, it was difficult to determine whether the pilot of the crossing aircraft even could have seen the last REL before crossing the runway centerline. This source of light busts could be ameliorated by decreasing the arrival distance parameter. That in fact has been done separately at the A and B intersections in south flow only, where the distance parameter was decreased from 3/4 to 1/2 nmi on 8 March 2005.

One light bust incident was caused by a rain clutter track moving on the runway, turning on RELs, and two aircraft being cleared to cross and actually crossing. Rain can cause the ASDE-3/Primagraphics surveillance to include large numbers of moving rain clutter tracks. The normal operating procedure for RWSL is to switch it to limited mode when AMASS is in limited mode. In RWSL, this causes the ASDE-3/Primagraphics track data to be ignored. When limited mode is not engaged during significant rain, RELs can turn on inappropriately. A method to reduce the probability of this occurring is to allow the RWSL system to switch to limited mode automatically when it detects significant numbers of false ASDE-3/Primagraphics tracks. An algorithm to accomplish this has been designed, implemented, and tested in the lab, and will be tested on a weather-available bases during the THL shadow operations tests at DFW in September.

The final REL light bust was an actual runway incursion that occurred on 8 March 2005. The pilot of the incurring aircraft was instructed to hold short of runway 18L at WK, read back the hold short instruction, but failed to hold short, with a B752 departure in progress. A callback to the pilot indicated he saw red RELs but decided to zip across the runway anyway due to high speed. RWSL was set to current level 4 at the time. Surveillance indicates a taxi speed of about 27 kt when the RELs turned on due to the departure and a distance of about 85 ft to the holdline. If the pilot had seen the RELs promptly after they turned on, he should have been able to stop the aircraft safely before it reached the holdline. Instead, he slowed slightly for a brief time, and then sped up again before he entered the runway. This problem can be helped by better pilot training and by increasing the RWLS light illumination to level 5.

The light bust problem has been largely resolved by changing the taxi-to-departure transition speed to 25 (and later 30) kt, and is expected to improve further if and when the TOR and automatic rain detection algorithms are made operational. Further tuning could reduce the light busts even more for arrivals within 3/4 nmi, with some loss of effectiveness.

11.5 Controller-Pilot Communications Impact

During the operational evaluation period, all communication over the DFW West local and ground frequencies at 124.15 and 121.85 MHz, respectively, were recorded. Those periods during light system operation (typically 7AM to 10PM local time) were made available for subsequent audition in order to log instances of communications concerning or caused by RWSL operation. Except where the voice recordings were unavailable due to computer error on 18, 26, and 28 March 2005, all even-numbered days in March were assessed. To make up for the three lost days, 25, 29, and 31 March 2005 were also assessed. Further assessment was stopped because the communications impact was found to be acceptably low even in the early learning phase of the evaluation.

All detected instances of RWSL-related controller-pilot communication are shown in Table 8. A total of 13 instances of such communication were found in the 15 days that were assessed. Ten of these instances were in the first half of the month; the RWSL-related communication tapered off after that. Based on the content of the communication, about half of the communication instances can be considered early learning chatter. Only three of the instances were initiated by the controller, and these were all near the beginning of the evaluation. Most of the communication concerning RWSL took place on the local channel. About half of the communication instances can be considered positive.

In sum, RWSL did not have a significant impact on controller-pilot communication during the assessed period.

Date	Positive/ Negative	Local/ Ground (bold if initiated by ATC)	Event Discussion
4 March	+	Ground	Positive comments; mentioned liking lights.
4 March	-	**Local**	Talked about having lights shut off.
4 March	-	**Local**	Talked about centerline lights flashing.
4 March	-	**Local**	Local asked pilot if red lights were on in front of them.
8 March	-	Local	Pilot queried ATC about operation of lights.
8 March	+	Local	Pilot's general comments about lights.
10 March	-	Ground	Pilot asks about the lights.
12 March	+	Local	Pilot comments about liking the lights.
12 March	+	Local	Positive comments; mentioned liking lights.
14 March	+	Local	Pilot comments about liking the lights.
24 March	+	Ground	Pilot query unintelligible. ATC responds with "operated through transponder and primary ground radar system." Apparently pilot asked how lights turned on and off.
24 March	+	Local	Pilot says, "Your red lights are cool."
25 March	-	Local	Pilot asked about lights not working or going out, though the recording is almost unintelligible.

Table 8. All detected RWSL-related controller-pilot communications in the assessed days.

12 Operational Feedback Analysis

12.1 Pilot Survey

The pilot survey comprised 18 yes/no response statements presented in a positive and negative counterbalanced order with additional comments encouraged. There were three survey methods: web site (at RWSL.net), telephone (toll free number 1-888-DFW-RWSL), and paper (placed near posters in Operations Centers). Most pilots used the website method to respond to the survey; the phone method was rarely used and is not included in this report because of insufficient response.

A total of 220 responses were received, 167 via the Web and 53 in paper form. (The survey was the same except the data entry mode differed.) An additional 13 incomplete surveys were received, but were not included in the final analysis. Surveys were collected over the whole operational evaluation period of three months starting 1 March 2005 and ending 31 May 2005. About 75 completed surveys were received each month.

Overall reaction to the RWSL program and the RELs was very favorable among the participants. An overwhelming majority of the respondents, 92%, felt that RELs would help reduce runway incursions, and 88% would recommend that RELs be installed in other airports. Only 26% of the respondents felt that the system needs some fine tuning in such areas as the configuration of the lights relative to the taxi way hold line, the timing of the lights, and the intensity of the lights. Only 6% of the respondents were expressly negative about the concept and/or its implementation.

12.1.1 Pilot Respondent Demographics

12.1.1.1 Employer

Table 9 below describes the demographic characteristics of the respondents. All the respondents were pilots or copilots.

Employer

AAL	EGF	Other	No response
159	35	16	10

Role

Pilot	Co-Pilot	No response	
129	57	34	

Experience (hours)

<10K	10–15K	>15K	No response
67	80	57	16

Table 9. Respondent demographics.

The majority of the respondents were American Airlines (AAL) employees. Specifically, 159 of the 220 respondents were employed by American Airlines (AAL), 35 by American Eagle Airlines (EGF), and 16 by other airlines including US Airways, United, Delta, Northwest, and FedEx. Ten respondents did not include their employer name in the survey.

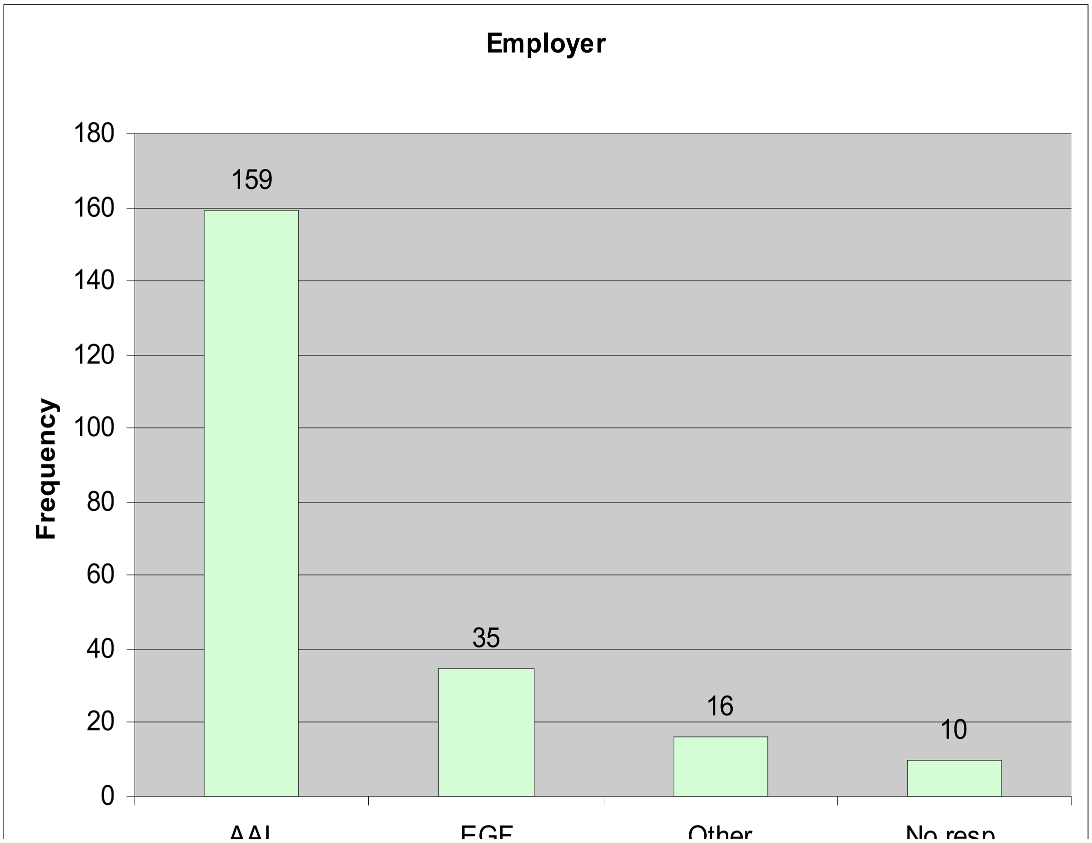

Figure 20. Frequency of respondents by employer.

12.1.1.2 Role

Most of the respondents were pilots. Of the 220 respondents, 129 were pilots, 57 were co-pilots and 34 did not report their role.

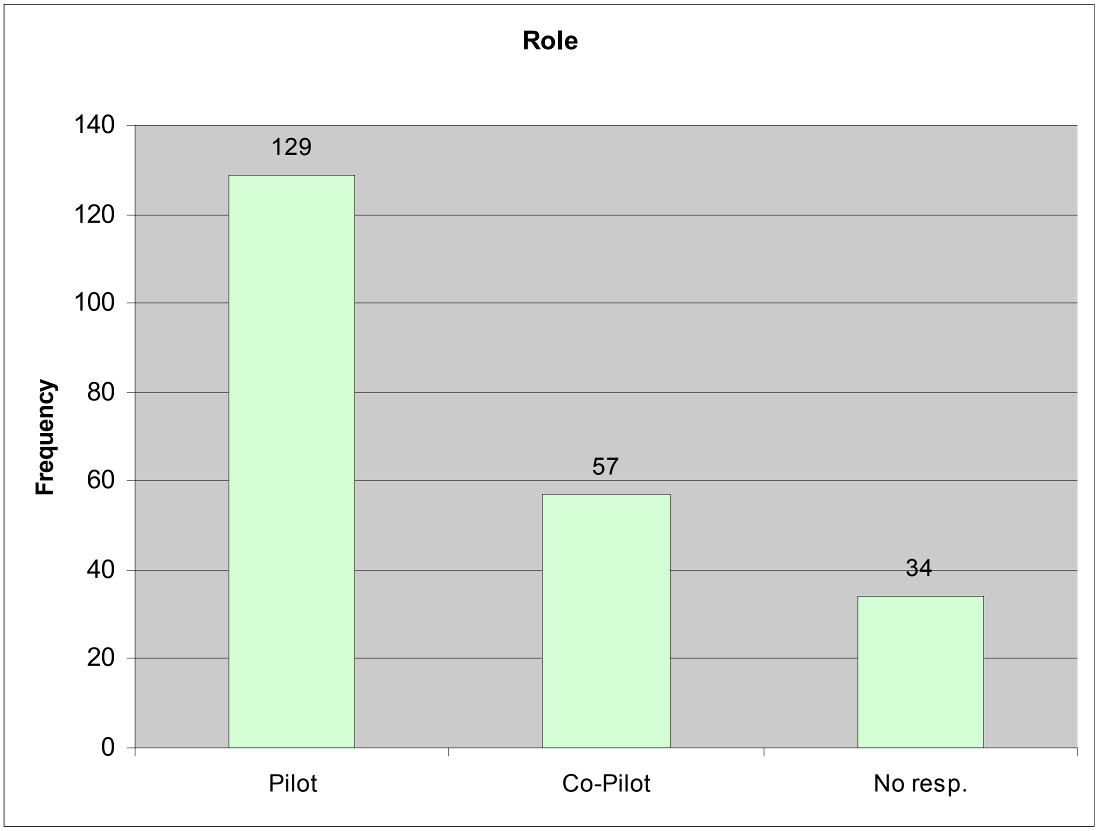

Figure 21. Frequency of respondents by role.

12.1.1.3 Flight experience

In terms of flying experience, 57 individuals had less than 10,000 flying hours, 80 individuals had flown between 10–15 thousand hours, and 67 individuals had flown more than 15,000 hours. Sixteen respondents did not report their flying experience.

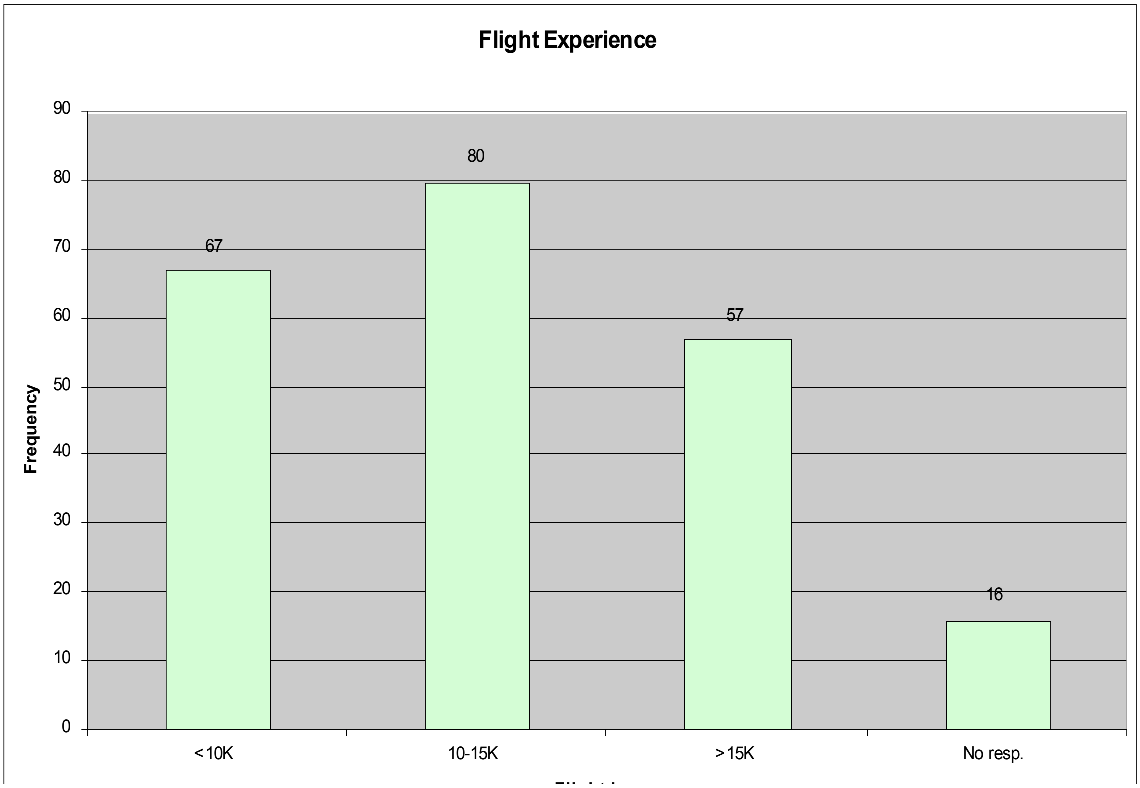

Figure 22. Frequency of respondents by flight hour categories.

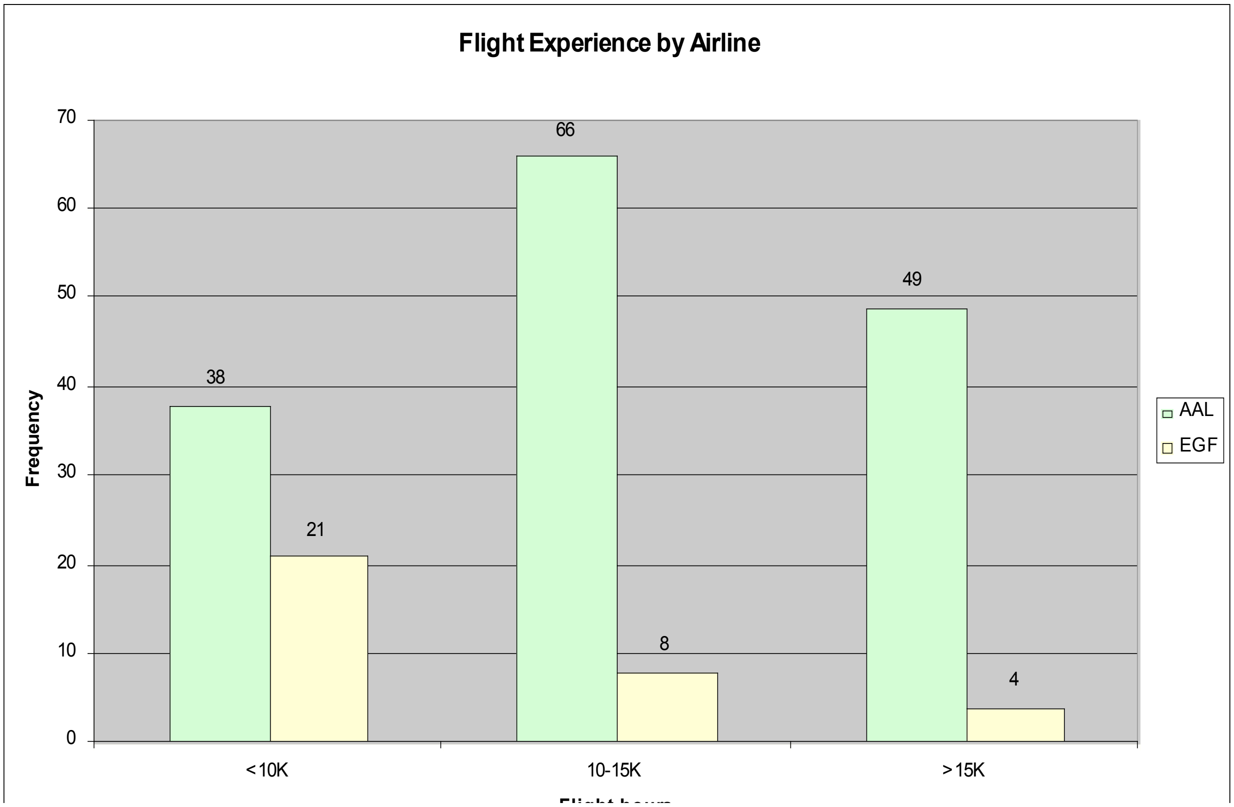

Figure 23. Frequency of respondents by flight experience and airline or employer.

The distribution of flying experience among the AAL respondents was skewed toward the high end of the scale. Forty-nine pilots had flown 15,000 hours or more, 66 pilots had flown between 10 and 15 thousand hours and 38 pilots had flown less than 10,000 hours. On the other hand, only 4 EGF pilots had flown more than 15,000 hours, while 8 had flown between 10 and 15 thousand hours and 21 EGF pilots had flown under 10,000 hours.

12.1.2 Pilot Respondent Experience with RELs

Of the 220 respondents, 21 respondents had not seen RELs at all while 199 had seen them at least once. Of these, 124 had seen the RELs 1–5 times, and 75 had seen the lights more than 5 times. The respondents who had not seen the lights in action answered only the questions that related to the concept of RELs, but not to specific operational concerns such as the "conspicuity of the lights" or "were they on while they were supposed to be off".

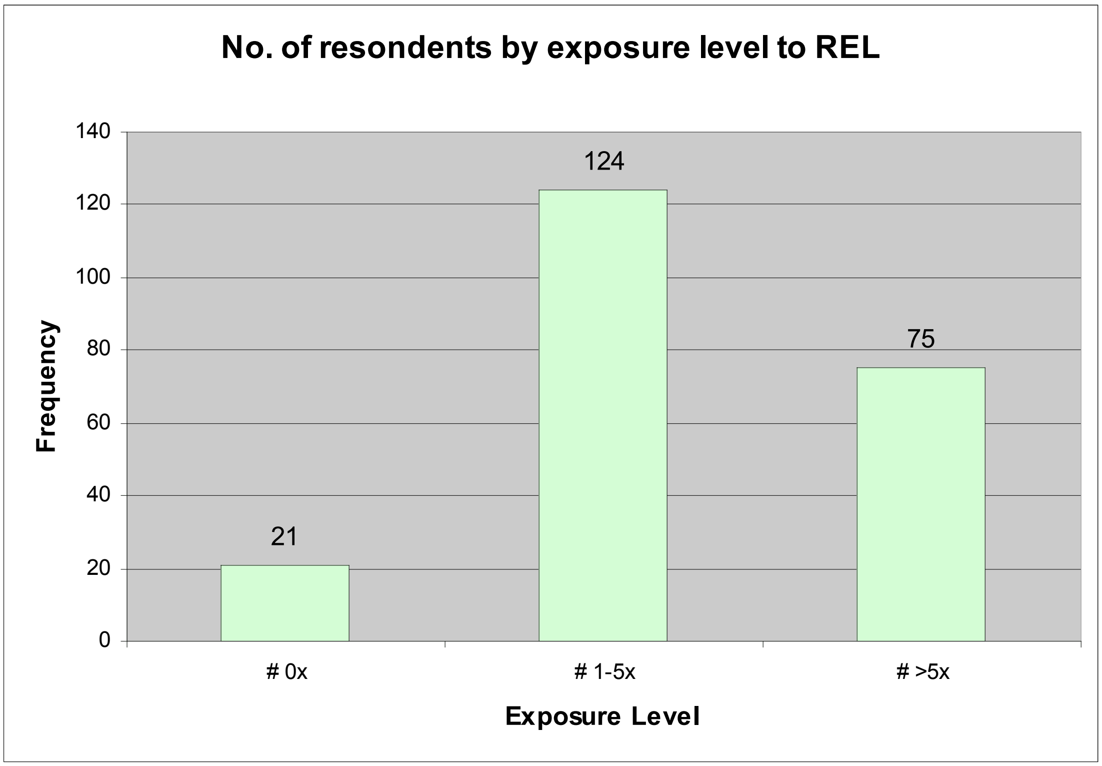

Figure 24. Frequency of responders by exposure to RELs.

12.1.3 Pilots Respondent Comments about RELs

Many respondents had strong feelings about the RELs. Of the 220 respondents, 129 respondents or 59% of the total respondents elected to add unstructured and open-ended comments to the survey. These comments, for the most part, reflected the pilots' personal attitude toward and concerns about the RWSL system. This is a relatively high percentage of added comments indicating the general interest and typically enthusiastic attitude that pilots felt about this system. Usually only 15–20 percent of the respondents add free form comments to such surveys, thus 59% is quite a high number. Ninety-one participants, on the other hand, did not add free form comment.

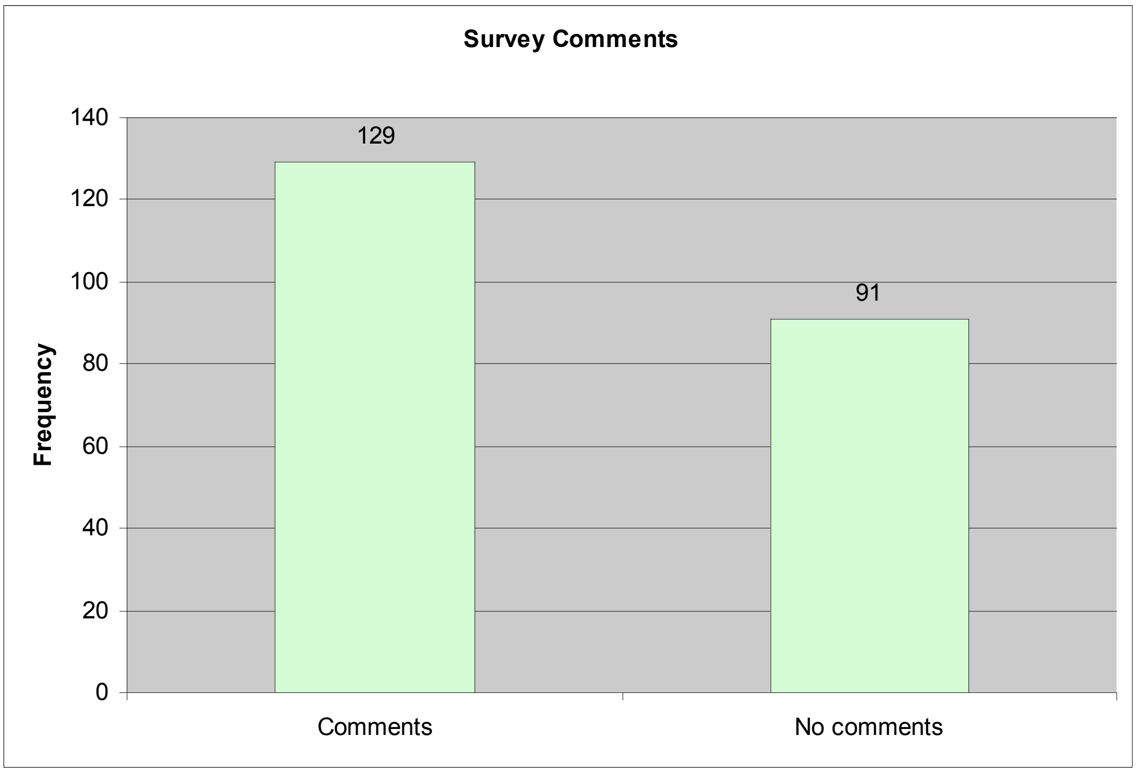

Figure 25. Frequency of responders by survey comments.

In reviewing the comments provided it appeared that most of the comments were specific and focused on one topic. A textual analysis of the content of each comment indicated that each comment could be categorized as either a positive comment or a critical comment, a comment that criticized an aspect of RWSL. The critical comments can be categorized into one of four categories. The first category was comments that were critical of the spatial **layout** of the lights relative to the taxiway, i.e. should they lights be parallel to the taxi way or perpendicular to it. The second category of critical comments was related to **timing** of RELs, i.e., the point in time when the lights come on or are turned off relative to the departing or landing aircraft. The third category of critical comments was related to the conspicuity or **visibility** of the lights, i.e., how easy or difficult is it to see the lights under different ambient illumination conditions. Finally, the fourth category of critical comments was related to general **negative** comments about RELs such as "this is a waste of money". Only eight comments could not be categorized (e.g., "observed RELs 3 times"), and nine comments included statements about more than one of the above categories.

Overall, the majority of comments were positive. Table 10 below depicts the nature and frequency of comments made by the survey respondents. Of the 129 comments received, 65 comments included positive statements about RELs such as "I do firmly believe that Runway Entrance Lights are an excellent idea". Seventy comments included some type of critical statement about the lights such as their spatial layout timing and intensity levels as well as negative comments about the concept, and a few included statements that fitted more than one category, e.g., a positive statement about the RELs as well as a suggestion to increase light intensity. Of these 70 comments, 27 addressed the spatial layout of the lights (e.g., perpendicular to aircraft movement rather than parallel), 18 addressed the visibility of the lights (too dim), and 12 the timing of the lights, i.e., lights go off slightly before the departing aircraft crosses the intersection (to allow for air traffic controllers' use of anticipated separation). Only 13 comments were explicitly negative in nature such as "waste of money" or "potential to confuse with runway guard lights".

	Positive	**Configuration**	**Timing**	**Visibility**	**Negative**
Number	65	27	12	18	13
Percent of comments	48.15%	20.00%	8.89%	13.33%	9.63%
Percent of total respondents	29.55%	12.27%	5.45%	8.18%	5.91%

Table 10. Nature of comments.

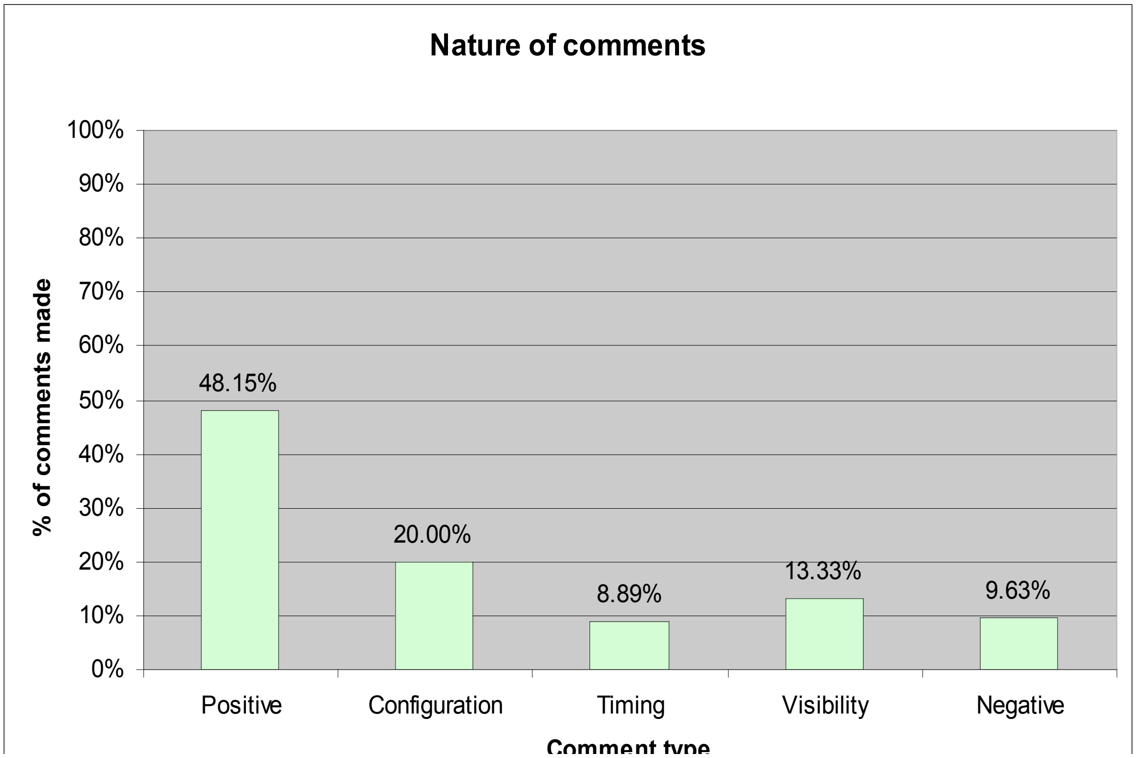

Figure 26. Percent of comment made by nature of comment.

Although the majority of respondents reacted quite favorably to RWSL, the concerns showed by the 70 respondents about one aspect of the lights or another should not be dismissed. This is a substantial portion of the respondents, about 32%, and their concerns should be investigated further. Thorough training and communication of the underlying logic of the system design and its operation could address some proportion of the critical statements.

12.1.4 Pilot Survey Statement Results

Table 11 below and the associated graph are a summary of the results for each statement in the survey. A chi-squared test of the responses to each statement indicated a significant favorable response, suggesting that responses to each statement were not due to chance, but rather due to favorable perception of RELs.

As can be seen in the graph below with the exception of responses to statements 14 and 15, at least 75% of the respondents answered each statement in a favorable way to RELs. Favorable in this case indicates a response that favors RELs such "would recommend RELs" or "will (not) cross red RELs".

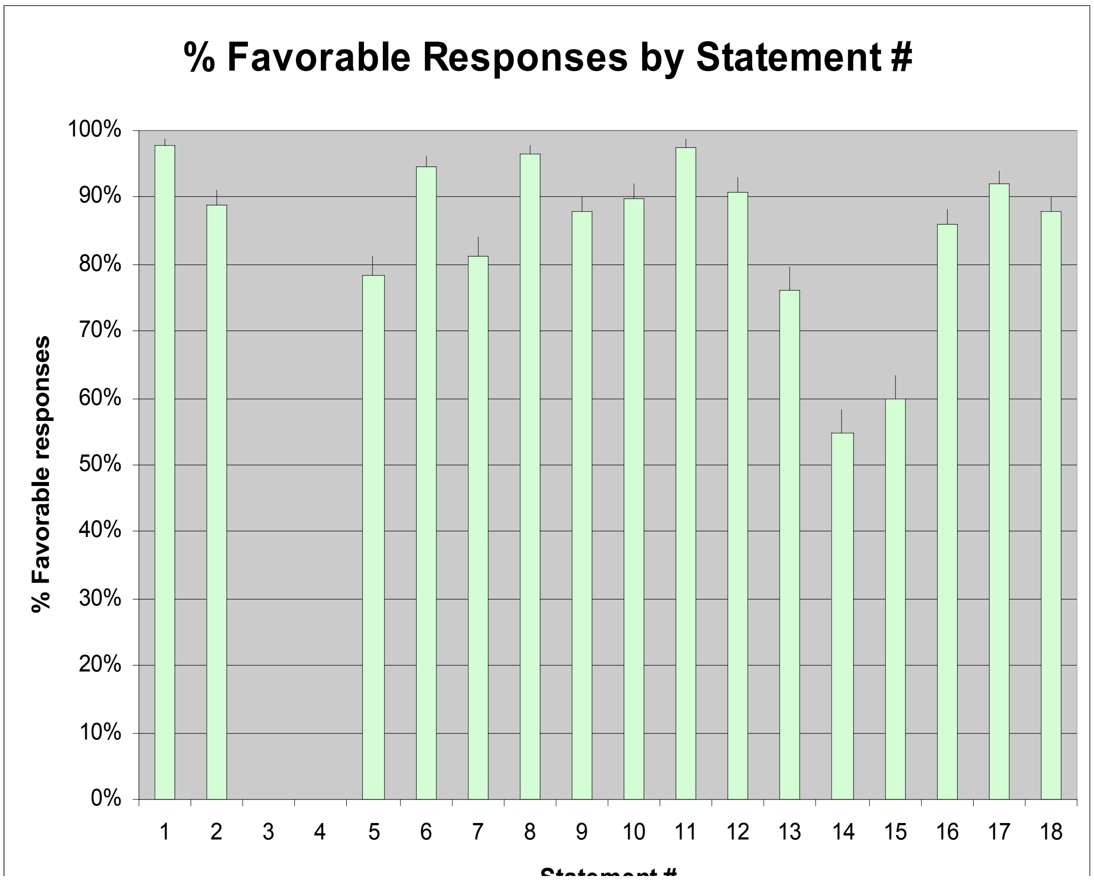

Figure 27. Percent favorable responses by statement number.

#	Question	# N	# Y	Total	Prop. N	Prop. Y	SD	% Fav	Prob (chi test)
1	Will cross in red	213	5	218	0.977	0.023	1.01%	97.7%	4.53E-45
2	Lights off is clear	190	24	214	0.888	0.112	2.16%	88.8%	7.62E-30
3									
4									
5	Lights conspicuous	43	156	199	0.216	0.784	2.92%	78.4%	1.14E-15
6	Consistent with clearance	11	189	200	0.055	0.945	1.61%	94.5%	2.50E-36
7	Verbal response increase	160	37	197	0.812	0.188	2.78%	81.2%	1.89E-18
8	Task completion impeded	192	7	199	0.965	0.035	1.31%	96.5%	2.72E-39
9	Enhance situational awareness	24	172	196	0.122	0.878	2.34%	87.8%	4.04E-26
10	Lights not functioning	178	20	198	0.899	0.101	2.14%	89.9%	2.95E-29
11	Lights incorrectly on	192	5	197	0.975	0.025	1.12%	97.5%	1.70E-40
12	Lights incorrectly off	179	18	197	0.909	0.091	2.05%	90.9%	1.85E-30
13	Conspicuous in low visibility	37	118	155	0.239	0.761	3.42%	76.1%	7.71E-11
14	Lights would have helped	96	117	213	0.451	0.549	3.41%	54.9%	0.150
15	Uncertain of location	87	130	217	0.401	0.599	3.33%	59.9%	0.0035
16	Confused with guard lights	177	29	206	0.859	0.141	2.42%	85.9%	6.24E-25
17	Help reduce incursions	17	196	213	0.080	0.920	1.86%	92.0%	1.40E-34
18	Would recommend	26	190	216	0.120	0.880	2.21%	88.0%	6.49E-29

Table 11. Summary of pilot responses to each survey statement.

12.1.4.1 Discussion of Pilot Survey Results

As stated above the overall response to the RELs as exhibited in the responses to the survey was very positive. Response to several key statements, however, deserves a closer look because of their operational criticality. The first and probably the most critical result in the survey is the response to statement number 17 which asked for pilot's opinion about the utility of the RELs. On the average 92% of the respondents felt that the RELs will help reduce runway incursion. It is interesting to note that 79% of even the respondents who were critical of RELs (included a critical statement in their comment) felt that RELs would help reduce runway incursions.

The utility pilots saw in the RELs was not at the expense of their workload or their situational awareness. More than 96% of the respondents felt that RELs will not impede their ability to complete their cockpit tasks, although a small minority, about 20% felt that RELs could increase their verbal response time. Again, similarly to the perception of RELs utility, there was no difference in the perceived impact of RELs on workload between respondents who were critical of RELs and those who were not. In fact, 94% of those who made a critical statement about the RELs felt that it would not impede their cockpit performance.

One possible reason why respondents felt that the RELs will not increase workload is that more than 94% of them felt that REL operation was consistent with their clearance. Thus RELs are perceived to be a redundant source of information that not only do not increase mental workload, but might even reduce it to some extent.

One result that was not very favorable to RELs was the perceived visibility or conspicuity of the light. Although 78% of the respondents found the lights to be sufficiently visible or conspicuous, 22% found the lights to be difficult to see. Among those respondents that a critical statement about the light in one way or another, only 49% found the lights to be sufficiently conspicuous or visible. Fifty one percent found the lights to be difficult to see. The issue of REL visibility was noted early in the operational evaluation, and as will be discussed elsewhere in this report. Efforts were made to rectify this problem by recommending that the lights should be set to a higher intensity level. It is interesting to speculate that the relatively large number of critical comments made about RELs was triggered by lights' conspicuity. Given that 51% of those who made such statements found the lights difficult to see, it is possible that this triggered an overall negative attitude toward RELs.

12.1.5 Pilot Survey Aggregated Results

To enhance comprehension of the survey results, responses to specific statements were aggregated into three indices: acceptance, comprehension, and perceived operational effectiveness. The acceptance score was based on responses to statements 9, 17, and 18, namely RELs enhances SA, will help reduce incursions, and will recommend additional installations. The comprehension score was based on responses to statements 1 and 2, namely will cross in red and lights off indicate clear to cross. The perceived operational effectiveness score was based on responses to statements 5, 6, 10, 11, and 12, namely lights are conspicuous, they are consistent with ATC clearance, lights were not functioning, and lights were off when they should have been on, or were on when they should have been off. These indices were formed after the survey administration and were based on the logic behind the different statements. Significant correlations found between the responses to each statement within each index verified the logical groupings and added legitimacy to aggregating the statements into these indices. The inter-statement correlations will be discussed later in this report.

Overall the respondents rated RWSL favorably. The large majority of the respondents (93%) understood or comprehended the operating procedures associated with RELs. Nearly all (98%) of the respondents stated that they will not proceed through illuminated RELs (statement 1), and 89% stated that they will not interpret the off state of RELs as clearance to proceed (statement 2). This later result also indicates that about 11% of the respondents felt that they might see turned off RELs as indication that they can cross. Given that this result could lead to runway incursions it will be important to deal with it in future iterations or RWSL either via design of the light system and or training.

The perceived operational effectiveness index was slightly lower than the other two indices with responses on its statement averaging about 88% vs. 93% for comprehension and 92% for acceptance.

The overall acceptance of the system based on the survey was above 90%. This result is the average score of the results of statement 9 — will enhance my SA, statement 17 — will help reduce runway incursions, and statement 18 — will recommend additional implementations.

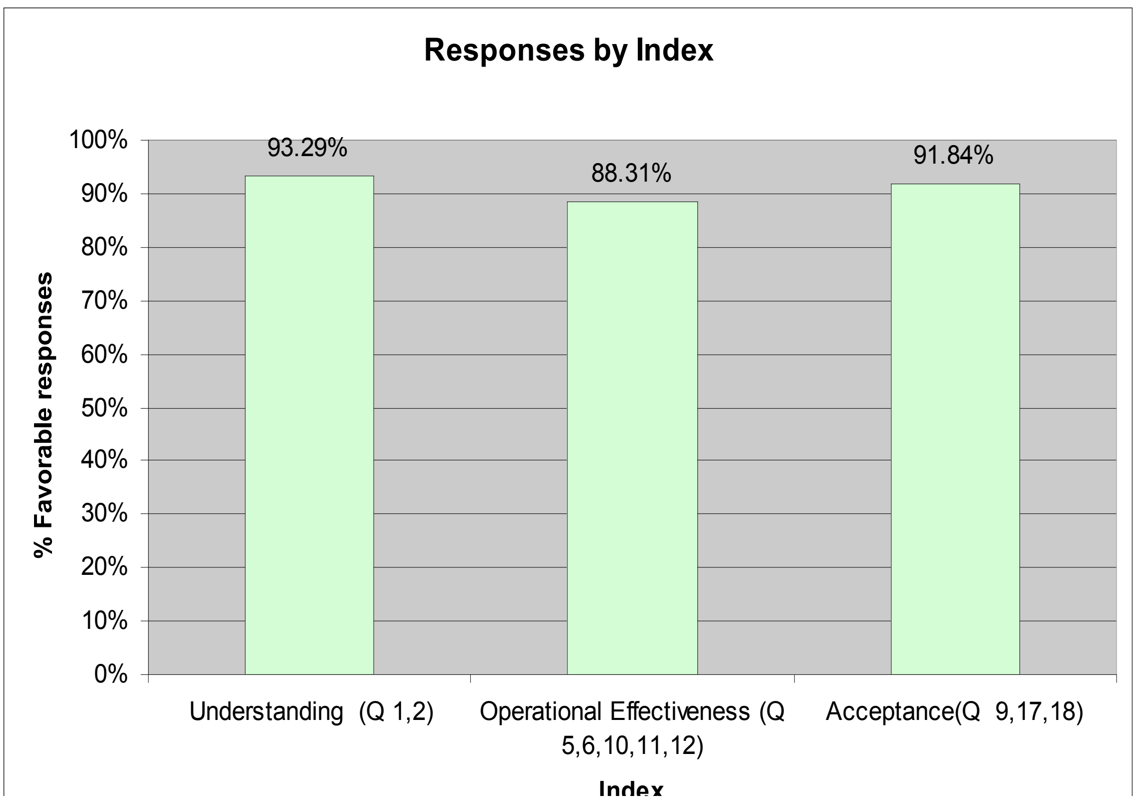

Figure 28. Responses by question category.

12.1.5.1 Responses by exposure to REL

The survey indices correlation with exposure to RELs is described in the next figure and following paragraphs. The operational effectiveness score for pilots with no exposure to RELs (see next figure) is missing because those individuals were asked to skip statements pertaining to this topic. If pilots were not exposed to RELs they could not report about how well they worked, so these questions were not relevant to them.

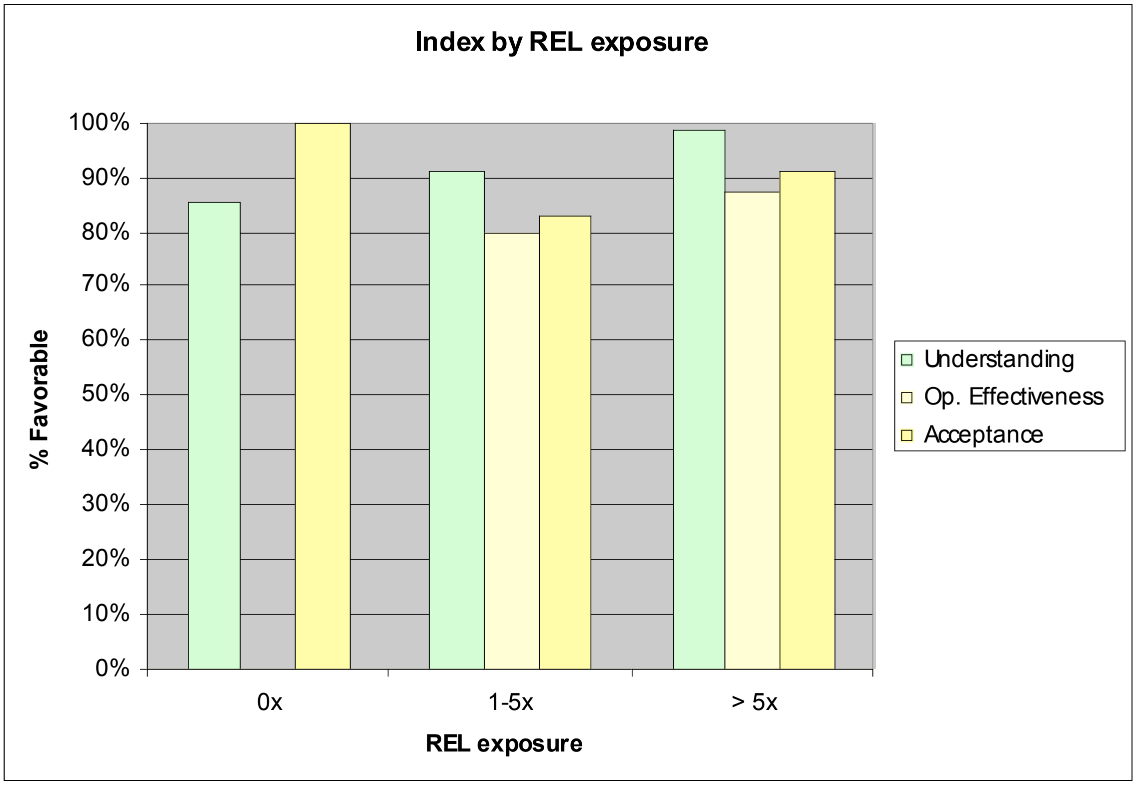

Figure 29. Responses by REL exposure.

As was expected, comprehension increased with exposure to RELs. It was lowest — 86% — for pilots who did not observe the RELs in operation, 92% for those who had 1–5 encounters with the lights, and was close to 99% for those who encountered the RELs 5 times or more.

The perceived operational effectiveness index was 80% for pilots who observed RELs 1–5 times and 87% for pilots who observed RELs more than 5 times. Pilots who had not observed RELs did not respond to the statements associated with perceived operational effectiveness. The lower perceived operational effectiveness score for pilots who had less than 5 encounters with RELs is likely to be primarily due to the understanding of how the lights work and where they are located. For example, to support anticipated separation the lights go off slightly before the landing or departing aircraft passes through the intersection. This could be perceived as light being turned off when they should have stayed on impacting how pilots responded to this statement. Likewise, pilot with fewer encounters with RELs might not know precisely where RELs are located on the taxiway and runway, thus they need to engage in visual search to locate them. This search could be interpreted by pilots as implying lower levels of light conspicuity.

Acceptance varied slightly by exposure to RELs with the highest acceptance level, 100%, demonstrated by individuals who did not experience the RELs. For these individuals the idea of RELs and its description as presented in the www.RWSL.org web site proved very logical and appealing. Acceptance level dropped for individuals who had 1–5 encounters with RELs. The results for these respondents show an acceptance level of 83%. One possible explanation for this drop in acceptance level is the associated perceived operational effectiveness of the system for this group of individuals. As will be seen later, individuals who experienced RELs 1–5 times rated its operational effectiveness lower than individuals who experienced it more than 5 times. Finally, the acceptance level for individuals who saw RELs 5 times or more went up to 92% and the associated perceived operational effectiveness increased as well.

12.1.5.2 Responses by flight experience

The influence of flight experience on the favorability scores for the three indices is depicted in Figure 30. Because some pilots (16) did not provide information about their flying experience, the results in the next figure are slightly different from the results described above.

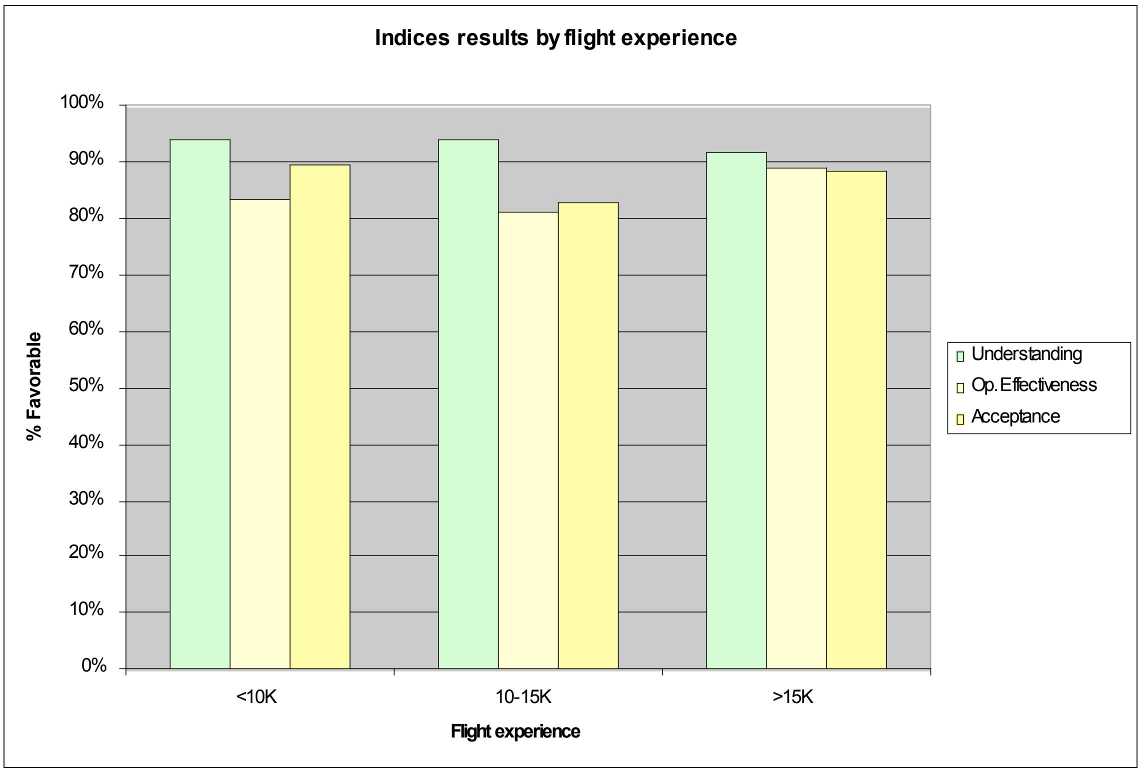

Figure 30. Responses by flight experience.

Comprehension of RELs operation did not vary much with flying experience. For the first two experience categories, comprehension was about 94 % and it was slightly lower for pilots who had flown 15,000 hours or more.

The effect of flight experience level on perceived operational effectiveness of RELs was relatively small and ranged from 81% to 89%.

Acceptance varied by flying experience. Pilots who had flown 10,000 hours or less responded most positively to RELs with a 90% acceptance level for this subgroup, which is important since most general aviation pilots would fit in this subgroup. For pilots who had flown 10–15 thousand hours, the acceptance level dropped to 83%, but it rose to 89% for pilots who had flown more than 15,000 hours.

12.1.5.3 Culture

The lowest favorable responses were to statement 14 — "I know of runway conflicts where the light would help" and 15 — "I have at times being uncertain of my location". These statements in a way ask pilots to provide information that even if they trusted the anonymity of the survey they probably would not give. The results on both of these questions were 55% and 60% favorable respectively and as can be seen in the figure below these scores were greatly below the scores on the other statements.

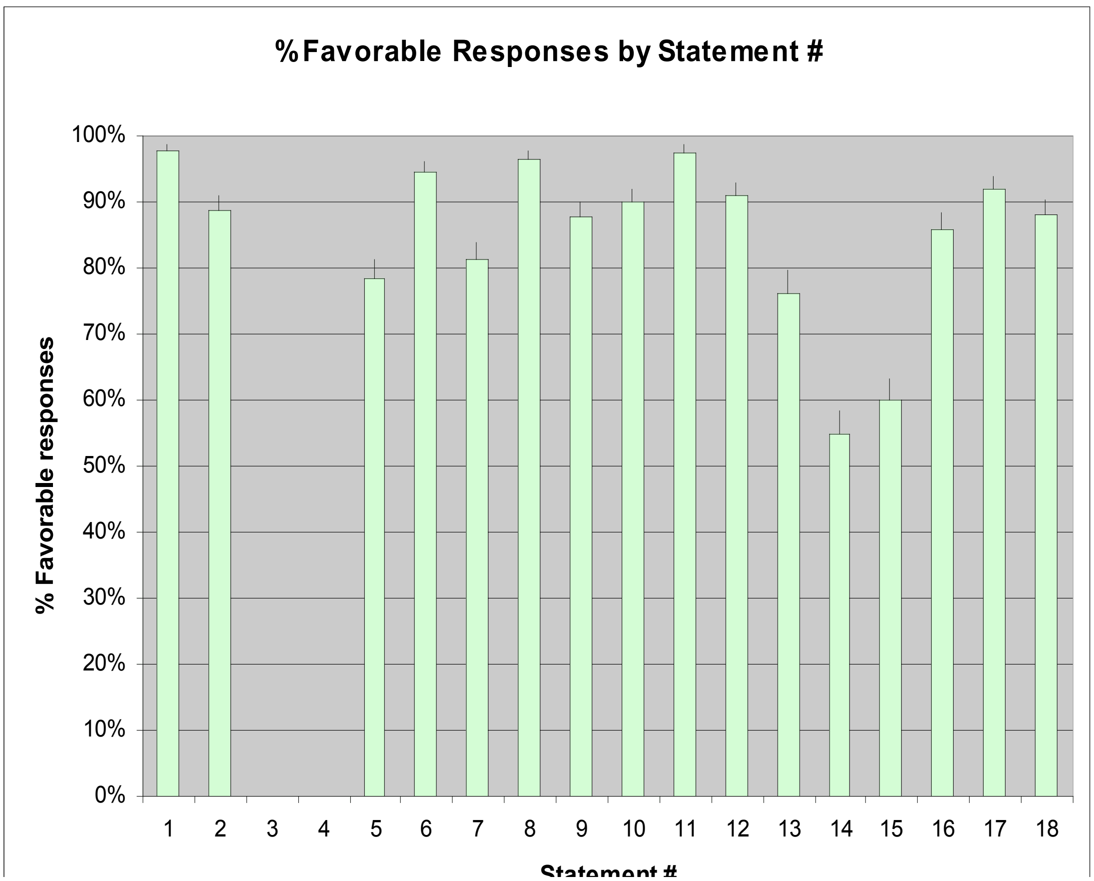

Figure 31. Percent favorable response by statement number.

12.1.5.4 Responses by critical comments

The table below compares the responses of individuals who made some sort of a critical statement about the RELs such as its spatial configuration, timing or light brightness, to those individuals who provided either positive comments about RELs or did not add a comment at all. As can be seen from the table with the exception of responses to a few questions, the differences between these two groups of individuals is relatively small.

	No or positive comment	Critical comment
1	97.3%	98.6%
2	90.0%	87.1%
3		
4		
5	80.0%	51.4%
6	86.7%	84.3%
7	79.3%	91.4%
8	98.0%	94.3%
9	84.7%	64.3%
10	92.0%	88.6%
11	97.3%	98.6%
12	94.0%	87.1%
13	61.3%	37.1%
14	54.0%	51.4%
15	59.3%	58.6%
16	90.7%	78.6%
17	94.0%	78.6%
18	91.3%	75.7%
Avg.	**84.4%**	**76.6%**

Table 12. Percent of favorable responses to each survey statement by respondent comments.

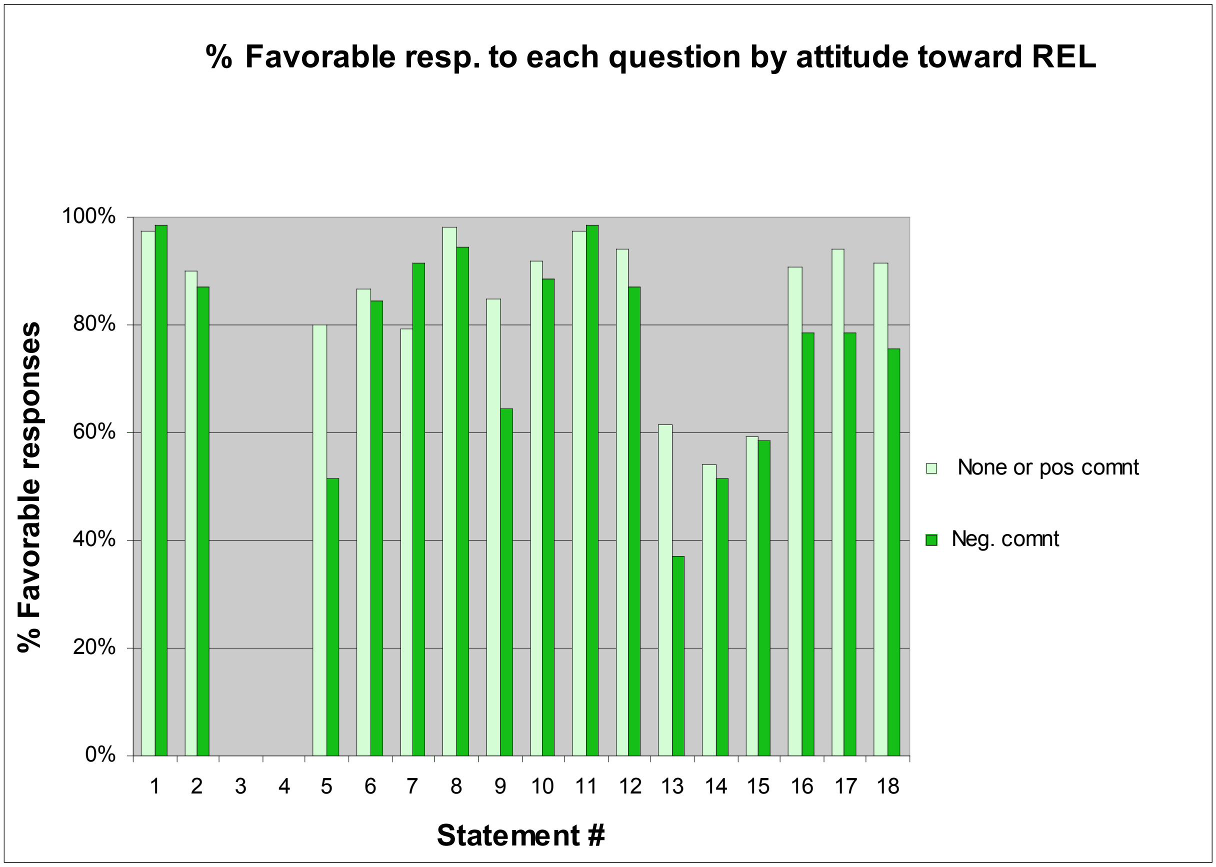

Figure 32. Percent favorable responses by "attitude" toward RELs.

As can be seen in the above table and diagram, the biggest differences between the responses of the two groups are on statements 5 and 13. Both statements address the visibility or conspicuity of the lights. Although there exists a minute-by-minute record of light intensity setting for the entire operational evaluation period, there is not an accurate or complete record of the specific encounter time of each respondent with the RELs. This obviously makes impossible the correlation of the actual light intensity setting with the respondents' responses to the conspicuity statement. It is reasonable to assume that the negative responses to light conspicuity were associated with lower intensity setting. Elsewhere in this report there is a more detailed discussion of light's intensity setting.

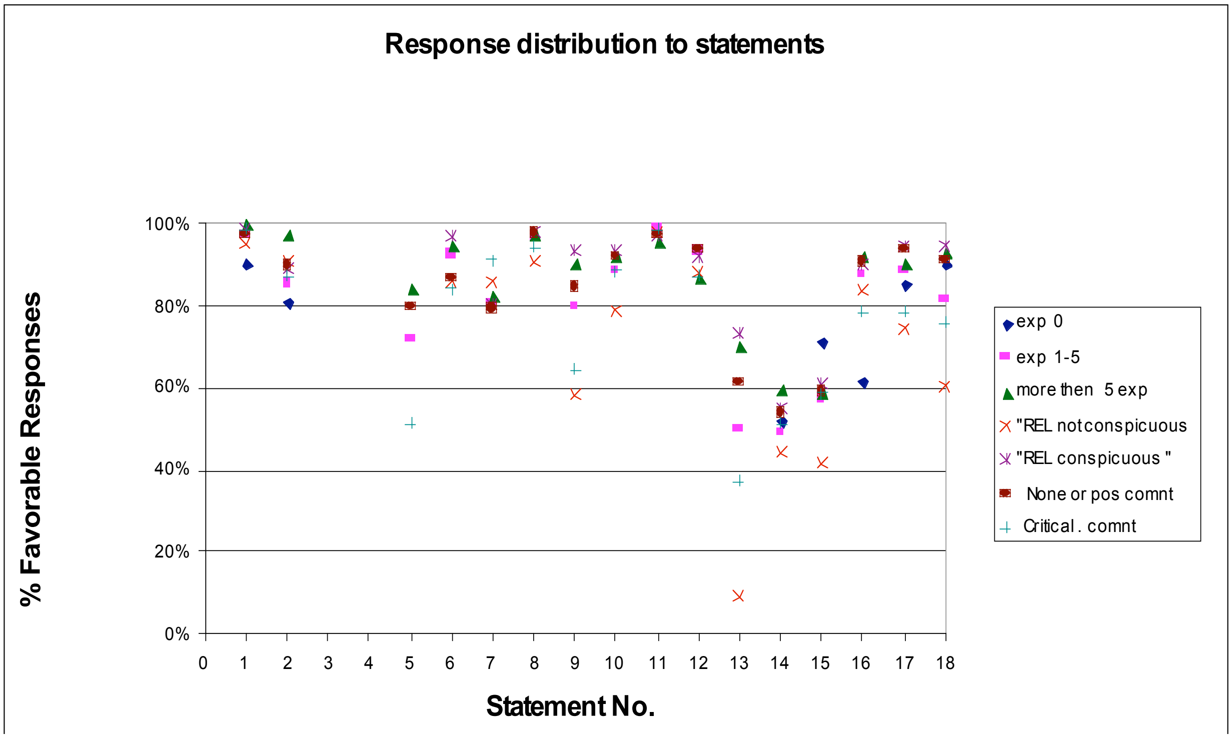

Figure 33. Percent of favorable responses to individual statement by experience with RELs, perception of light conspicuity, and attitude toward RELs.

The above graph describes the response data from three different perspectives: experience with RELs, perception of light conspicuity, and whether respondents made a critical comment or not. These perspectives are not independent of each other hence they do not lend themselves to comparisons such as response of individuals who found the lights to be conspicuous to those of individuals who experienced RELs more than 5 times. It is interesting to note that with the exception of a few statements, average response to the various statements was not affected by the above variables. The visible exceptions above were responses to the statement about conspicuity of the lights and situational awareness. Individuals who responded that the lights were not conspicuous overwhelmingly responded that the lights were not conspicuous in low visibility. Also individuals who stated that the lights were not conspicuous or included a critical comment in their survey were less likely to find the RELs to enhance their Situational Awareness than individuals who found the lights conspicuous and did not find fault in the current design of the lights.

12.1.6 Pilot Survey Correlation Matrix

In order to verify that similar survey questions indeed measure the same thing and to support the aggregation of statements to indices, an inter-correlation analysis was performed. In this section, all the inter-correlations that were significant at $p<.01$ are described.

The strongest correlations were for statements 18 and 17. Both statements relate to acceptance of the RELs. Statement 17 is about the perception that RELs will reduce runway incursions, and statement 18 is about recommending additional implementations of RELs. According to the correlation matrix, individuals who stated that they would recommend additional implementations of RWSL (statement 18) were also likely to state that RWSL will help reduce runway incursions and will enhance pilots situational awareness (statement 9). These correlations are logical and reinforce the notion of a general acceptance factor that comprises responses to statements 9, 17, and 18. These correlations are further reinforced by some of the lower correlations that were found.

In general it was observed that individuals who stated that they would recommend additional implementations of RWSL also stated that RELs did not impede their ability to complete normal cockpit duties (statement 8), that they found RELs to be conspicuous in general as well as under low visibility conditions (statement 13), and are less likely to confuse RELs with Runway Guard Lights (statement 16). These results suggest that the belief that RWSL can reduce runway incursion and add value to pilots' situational awareness is strongly related to pilot willingness to recommend additional installations of RWSL.

It is interesting to note the high degree of similarity in the correlation pattern of statements 18 and 17. Not only were these two statements correlated with the same statements, but also the correlations were in the same direction with each question and about the same magnitude. According to the correlation table, individuals who responded positively to the statement that RWSL would help reduce runway incursions (statement 17) were also likely to feel that RELs enhances their situational awareness (statement 9). These individuals were unlikely to state that RELs were not functioning (statement 10). This negative correlation of course is quite logical since individuals who think that RELs is not functioning are not likely to think that it will help reduce runway incursions.

Individuals who stated that RELs enhance their situational awareness (statement 9) were also likely to state that RELs will not be confused with Runway Guard Lights (statement 16). These individuals are also likely to state that RELs does not impede their ability to complete their cockpit duties (statement 8).

Several statements addressed the perception of how well RELs operated. These statements included the conspicuity of RELs (statement 5) and conspicuity in low visibility (statement 13), consistency of light operation with clearance (statement 6), RELs were on when they should have been off (statement 11) or off when they should have been on (statement 12), and RELs were not functioning (statement 10). Although these statements were not all inter-correlated, there were many significant correlations among them to suggest that they address a common factor – perception of RELs operation. The statement that RELs operation was consistent with clearance (statement 6) correlated negatively with the perception that RELs were off when they should have been on (statement 12) and they correlated positively with responses to the statement that RELs were not functioning (statement 10). Although causality cannot be deduced from correlation, it might be safe to hypothesize those individuals who thought that RELs were off when they should have been on also felt that RELs were not functioning and naturally that their operation was inconsistent with their clearance. Statement 6 also had a negative correlation with statement 8, the ability to complete cockpit tasks. In other words individuals who felt that REL operation was not consistent with their clearance also felt that RELs impeded their ability to complete cockpit duties.

An important result of the data analysis is that acceptance correlated significantly ($p>.05$) with conspicuity of the lights. This result suggests that to maximize acceptance, the conspicuity of the lights or the ability of pilots to see the lights clearly needs to be maximized.

A noteworthy result in the correlation table is the absence of correlation between statement 1 and statement 2. The first is proceeding through illuminated red lights when cleared to cross and the second is interpreting RELs turning off as clearance to proceed. Initially these two statements were expected to correlate and indicate comprehension of RWSL; however it is possible that due to its novelty, pilots still feel that they should follow ATC instructions immediately, rather than question the the lights.

An interesting pattern that emerges from the above correlations is that of a general positive and negative attitude toward the concept of the RWSL. Individuals who have a positive attitude were likely to respond in a positive or a favorable way to all the critical statements. These individuals were likely to state that their ability to complete cockpit duties were not impeded due to RELs, their situational awareness is enhanced due to RELs, RELs were clearly visible even under low illumination and that RELs will not be confused with Runway Guard Rails. These individuals feel RELs will help reduce runway incursions and therefore would recommend additional installations.

On the other hand the negative attitude group (much fewer in number) seems to be characterized by negative responses to statement 6 –RELs operation consistent with clearance. This group of individuals also was likely to feel that RELs would impede their ability to complete cockpit duties, think that RELs were not functioning, that were off when they should have been and were on when they should have been off. It is interesting to note that while perception of consistency of RELs operation with clearance did not correlate with utility perception of RELs (statement 17), impediment in cockpit duties (statement 8) did correlate strongly with perception of the utility or value of RELs (statement 17) and willingness to recommend additional installations. It is important to keep in mind that although the correlation matrix seems to suggest a positive and negative attitude group, it does not suggest the size of this group. From the analysis of the comments and the summary data it is clear that size of the "negative group" is quite small.

Employer, flight experience, and role did not strongly correlate with any of the statements in the survey. The only strong correlation for these variables was, as expected, between flight hours and role: pilots had greater experience than co-pilots. Overall these results indicate that attitude and perception of RWSL and RELs are general rather than specific to a given population.

12.2 Vehicle Operator Survey

Vehicle operators permitted to drive on and across runways were surveyed for their reaction to REL operation. The pilot and vehicle operator surveys were identical, although the order of the statements differed somewhat between the two surveys. As can be seen in Table 13 and Figure 34, vehicle operators were somewhat less favorable toward RELs. Unlike the pilot population, a larger proportion of the vehicle operators felt that RELs would increase their verbal response time. Also, a smaller percentage of vehicle operators felt that RELs would help reduce runway incursions and therefore would not recommend additional installations.

#	Statement	# No	# Yes	Total	% Favorable
1	Will cross in red	17	1	18	94%
2	Lights off is clear	17	1	18	94%
3	Saw lights 1	0	18	18	100%
4	Saw lights >5	3	15	18	83%
5	Lights conspicuous	3	15	18	83%
6	Consistent with clearance	4	14	18	78%
7	Verbal response increase	10	8	18	56%
8	Task completion impeded	17	0	17	100%
9	Enhance situational awareness	1	17	18	94%
10	Would recommend	6	12	18	67%
11	Help reduce incursions	6	12	18	67%
12	Lights not functioning	13	5	18	72%
13	Lights incorrectly on	16	2	18	89%
14	Lights incorrectly off	14	4	18	78%
15	Uncertain of location	17	1	18	94%
16	Confused with guard lights	18	0	18	100%
17	Conspicuous in low visibility	1	17	18	94%
18	Lights could have helped	1	17	18	94%

Table 13. Summary of vehicle operator responses to each survey statement.

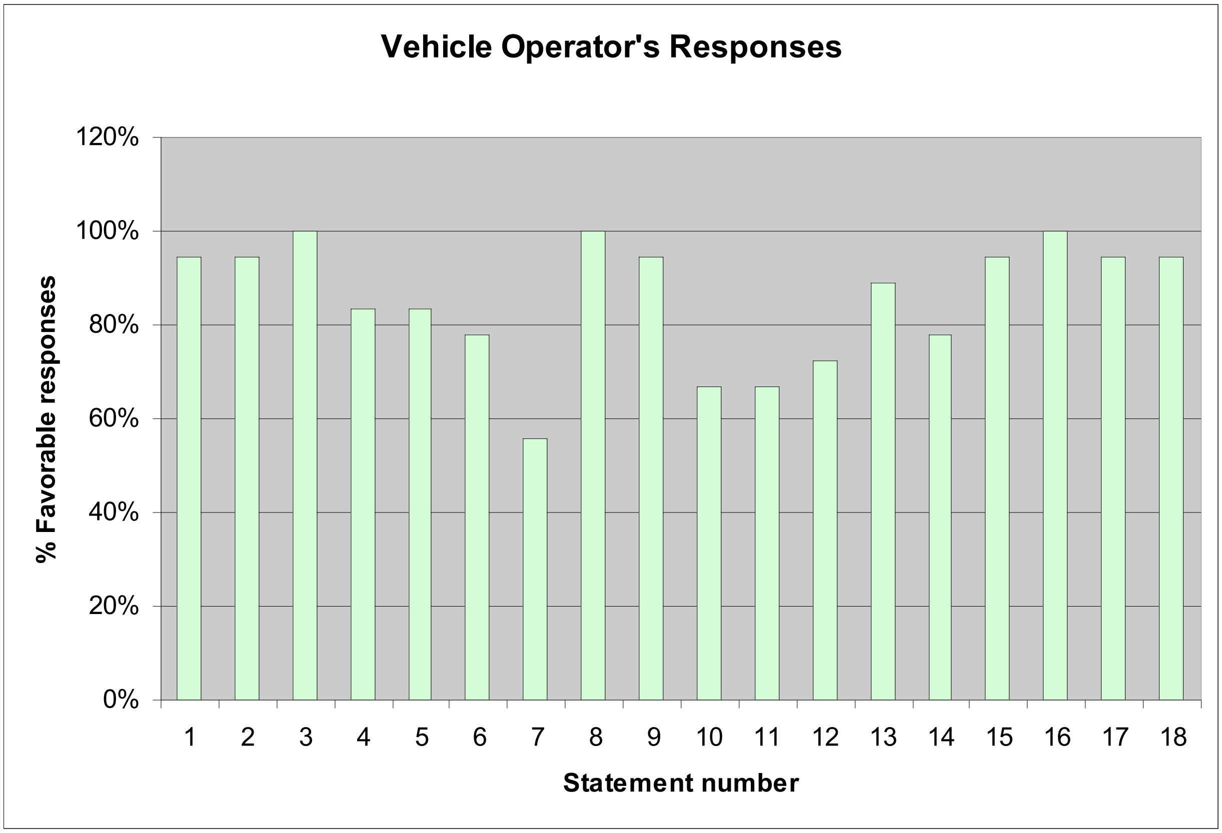

Figure 34. Percent of favorable responses by vehicle operators on each statement.

When looking at the above data it is important to remember that the sample size of vehicle operator survey was only 18. Such a sample size is very low for a survey and results in relatively unstable results, i.e., each response change in the survey by a single individual will strongly impact the overall result of the group. In particular, if one individual changed his or her mind on a single statement, this would mean a swing of 5.5% in the overall favorable responses to that statement.

13 Conclusions

13.1 Main Results

The operational evaluation of runway entrance lights at DFW clearly indicates that:

- RELs work technically, operationally, and conceptually.
- Pilots perceive RELs to be a safety aid that could help reduce runway incursions.
- RELs do not impose significant workload on pilots or controllers.
- RELs do not interfere significantly with normal, safe operations.

- RELs do not cause a significant increase in controller-pilot communications.

- The vast majority of the pilots surveyed would recommend the installation of RELs at other airports.

13.2 Recommendations for Future Work

There are significant conclusions that indicate further work is required:

- Correct operation of RELs requires excellent surveillance. The ASDE-X prototype at DFW needs to be improved to mitigate the frequency of missing multilateration tracks, track gaps, track splits, and false tracks. A means should be provided within the ASDE–X to detect and correct RU miswiring errors.

- The algorithm for turning off RELs when a departure becomes airborne needs to be improved to avoid the problems associated with fast ground bit and sticky ground bit operation.

- Some transponders report altitudes that are usually quantized at a 100’ resolution, but sometimes at a 25’ resolution. This behavior and its effect on the airborne algorithm need to be understood better.

- REL operation for aircraft taxiing or other vehicles driving on the runway should be suppressed to allow runway crossings downfield of such activity. The RWSL state machine should be augmented to identify such activity on the runway.

- REL configuration is the most frequent issue identified by pilot survey respondents. This issue has been investigated previously, and in fact that investigation led to the current implementation of the RELs along the taxiway centerline from the holdline to the runway edge, with an additional light at the runway centerline. If this configuration is to be maintained, pilot training should include more information concerning its motivation.

- Light intensity was raised as a question by a minority of the pilot respondents. To help air traffic to maintain the light intensity level appropriate for the time of day, the system should allow automatic current level selection with time offsets relative to sunrise and sunset times or based on photometric measurement of ambient light conditions.

- The pilot survey results were largely reducible to three indices: acceptance, comprehension, and operational effectiveness. The list of statements should be reviewed and may need to be expanded to include other concepts that need to be studied. In addition, some questions could be rephrased to insure that they are correctly understood. Furthermore, some questions could be added to allow internal validation of the survey results. Additionally, a new, more targeted survey could be developed for repeat evaluators.

- The RWSL website served as a useful information release method and as an electronic survey host. The structure of the website could be improved to incorporate new elements such as a What’s New page, Frequently Asked Questions, and Testimonials. The training could be enhanced and an online quiz employed to improve pilot understanding of the purpose and timing of the light operation.

Addressing the above issues will significantly enhance RWSL operational compatibility and improve pilots' experience with RELs and their perception about their effectiveness and utility.

14 Summary

Runway status lights shown directly to pilots and vehicle operators offer the potential to reduce runway incursions and runway conflict accidents by increasing overall situational awareness of the dynamic runway environment. The operational evaluation phase of RWSL was a live test with actual traffic and a limited deployment of a field lighting system, with a presence in both the operational tower and the observation tower in order to prove the runway status lights concept. The operational evaluation test period provided critical technical performance and operational feedback information required to assess the suitability and correctness of operation of RWSL in providing an important safety function. The operational evaluation proved the RWSL concept meets the key high-level requirements; that the runway status lights operate automatically, that no controller action is required for their operation, that the lights accurately depict runway status to pilots and vehicle operators, and that the lights do not interfere with normal safe surface operations. The operational evaluation constitutes for the runway entrance lights the final phase of the RWSL research and development program culminating in a prototype deployment. The results of the operational evaluation will serve as validation to continue the deployment of runway status lights at other busy airports in the NAS and for further evaluation at DFW.

15 References

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4. RWSL Research Management Plan, August 2002.

5. RWSL Engineering Test Plan, March 2002.

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